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16. ABSTRACT

A project was initiated to determine the feasibilwty of assessing and classifying a group of Illinois lakes through the utilization of a combination of contact- and satellite-acquired data. LANDSAT multispectral scanner (MSS) digital multidate data for 145 Illinois lakes were extracted from computer-compatible tapes and adjusted through regression analysis to a common acquisition date. Next, MSS lake pixel counts were converted to lake surface area estimates. Regression models employing transformed Mss bands as independent variables were developed for the estimation of several water quality parameters and two multivariate trophic state indices. The water quality parameter estimates were then used to develop lake rankings that, when evaluated, were found to be in general agreement with ancillary data. Complete linkage-based cluster analyses of the raw MSS data and the LANDSAT-derived water quality parameter estimates for the 145 lakes resulted in the identification of physically significant lake groups, each of which may be characterized by its overall quality, physical and chemical properties, biology, watershed factors, morphology, and use impairment. LANDSAT, when used with the appropriate calibration data, is capable of providing a comprehensive, objective, rapidly acquired, synoptic view of lacustrine quality and use impairment. It is a flexible, cost-effective means for monitoring lakes on a Statewide basis.

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TROPHIC CLASSIFICATION OF SELECTED ILLINOIS WATER BODIES

Lake Classification Through Amalgamation of LANDSAT Multispectral Scanner and Contact-Sensed Data

by

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FOREWORD

Protection of the environment requires effective regulatory actions that are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report describes in detail a project utilizing a combination of LANDSAT-1 multispectral scanner data and contact-sensed data for the classification of selected lakes and artificial reservoirs in Illinois. It provides trophic rankings and classifications for 145 Illinois water bodies based on trophic indicator and multivariate trophic index estimates derived, in part, from satellite-acquired data. The information will be used by the Illinois Environmental Protection Agency in one segment of its program to meet the Federal mandate requiring the State to identify and classify, according to trophic condition, all publicly-owned freshwater lakes (Public Law 92-500, Section 314). The report will also provide useful information to other governmental agencies and organizations in the private sector that are considering the use or are already using LANDSAT in a lacustrine trophic classification program. Further information on this subject can be obtained from the Advanced Monitoring Systems Division.

George B. Morgan

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Director
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SUMMARY

This report describes the specific techniques utilized to generate a satellite-based classification of 145 Illinois lakes and interprets and disseminates the resultant products and ancillary information. The report represents one segment of an ongoing effort of the Illinois Environmental Protection Agency (IEPA) to meet the mandates of Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972 and Public Law 95-217, the Clean Water Act of 1977. Under Section 314-a of both laws, the multifaceted legislation requires that each State prepare or establish, and submit to the EPA Administrator for his approval:

> "(1) an identification and classification according to eutrophic condition of all publicly-owned fresh water (sic) lakes in such State; (2) procedures, processes, and methods (including land use requirements), to control sources of pollution of such lakes; and (3) methods and procedures in conjunction with appropriate Federal Agencies to restore the quality of such lakes."

The State of Illinois has over 80,000 impoundments, of which 2,700 have surface areas of 2.4 ha or more and are classified as lakes by the Illinois Department of Conservation. In light of the Federal mandate and the magnitude of the task (Illinois has about 775 publicly owned lakes), the IEPA elected to investigate new approaches to the lake classification problem. To receive serious consideration, an approach had to have the potential of being cost effective and rapid and of yielding results of practical value.

The approach described in this report employs a combination of satellite-acquired and contact-sensed data along with multivariate statistical techniques to classify a group of Illinois lakes. The remote sensor under consideration is the multispectral scanner (MSS) on board NASA's LANDSAT-1.

LANDSAT MSS data acquired October 14-16, 1973, for 145 Illinois water bodies were extracted from computer-compatible tapes (CCT's) using a digital image-processing system at NASA's Jet Propulsion Laboratory (JPL). Counts of picture elements (pixels), the MSS's basic unit of spatial resolution, were transformed to lake surface area estimates. LANDSAT MSS digital number (DN) mean values for each spectral band were adjusted to a common date using regression analysis. The date-adjusted MSS data were then examined for the existence of natural groups or clusters by applying a complete linkage clustering algorithm to the four LANDSAT-derived spectral measurements made on each lake.

Two multivariate trophic indices were developed through principal component analyses of five trophic indicators (chlorophyll *a*, inverse of Secchi depth, total phosphorus, conductivity, and total organic nitrogen) measured in 1973 by the U.S. Environmental Protection Agency's (EPA) National Eutrophication Survey (NES). Next, three sets of regression models were developed from the contact-sensed and remotely sensed data for 22 NES-sampled lakes. Four trophic indicators (chlorophyll *a*, inverse of Secchi depth, total organic nitrogen, and total phosphorus) and the two multivariate indices were treated as dependent variables; the four LANDSAT MSS bands (including standardized and transformed versions) were utilized as independent variables. The three sets of regression models were then extended to the remaining 123 lakes in the study group. Next, the 145 lakes were ranked by each of the four trophic indicators, a composite trophic rank parameter, and each of the two multivariate trophic indices using the LANDSAT-derived regression model estimates. In addition, complete linkage clustering algorithms were employed to delineate lake groups or clusters using the estimated values of four trophic indicators (Secchi depth, chlorophyll *a*, total organic nitrogen, and total phosphorus) for the 145 lakes. Interpretation and validation of the classification results were augmented by a lake water quality data base acquired by the State of Illinois in its 208 planning effort in 1977 and ancillary data from other sources.

The analyses of LANDSAT multispectral scanner (MSS) and near-concurrent contact-sensed data and ancillary information for 145 Illinois water bodies indicate that lake clusters can be derived from LANDSAT MSS raw data and MSS-estimated trophic indicator values. Each cluster is distinctive and identifiable in terms of general water quality, use impairment, and lake characteristics.

MSS data can also be used with contact-sensed data to develop regression models to provide relative estimates of Secchi depth, chlorophyll *a*, total organic nitrogen, total phosphorus, and two multivariate trophic state indices. Although less accurate and precise than contact-sensed trophic indicator values, the LANDSAT-derived parameter estimates can be used to develop generalized rankings of Illinois lakes. Regression models developed from MSS and contact-sensed data for lakes with large parameter value ranges and minimal contact-sensed data were more effective for the Illinois lakes studied when spectral ranks rather than normalized spectral data were used. Parameter estimation models developed from raw MSS data were least reliable.

Lacustrine water quality and use impairment in Illinois are significantly impacted by suspended particulate matter. Lake morphology and hydraulic factors affect the suspensoid load and general water characteristics. The best quality lakes studied were generally deep, for Illinois, with long retention periods (one year or more). Water quality and general use potential decreased for lakes with shorter retention times and shallower depths; generally the upper portions of reservoirs (areas of major stream inflow) exhibit increased use impairment. Although all of the study lakes are affected by high levels of phosphorus, overall water quality is basically influenced by suspended particle impacts on water transparency.

In other geographic areas, LANDSAT-derived lake surface area estimates have exhibited excellent correspondence with area estimates derived from concurrently acquired aerial photography; such imagery was not available for use in this project. The LANDSAT MSS provided surface area estimates generally within 10 percent of values derived for the study lakes from State of Illinois data files.

The LANDSAT MSS is an economically viable tool for the acquisition of data from all Illinois lakes and artificial reservoirs of significant areal extent (i.e., four or more hectares). The extraction and processing of lake MSS data is effectively accomplished, both costwise and timewise, through the use of an image-processing system recently developed by the JPL for lake classification purposes.

By virtue of its repetitive coverage, synoptic overview, and ability to generate permanent records amenable to automated image-processing techniques, the LANDSAT MSS is attractive for purposes of environmental assessment and monitoring. In this study LANDSAT provided a view of the past; it also provides a monitoring strategy that is objective, uniform, frequent, resource tolerant, and cost-effective for the future. However, LANDSAT is not a panacea; there are limitations and problems associated with it. A number of problems were encountered during the study (e.g., a very limited selection of cloud-free imagery, missing MSS internal scene calibration data, atmospheric effects). Most of the problems encountered during this study were successfully addressed. From the perspective of the State, this project was highly successful, both in the insights that were gained while addressing these problems and in the development of a high quality, comprehensive, objective, short-term data base on Illinois lakes.

The following recommendations are made in light of the study results and are consistent with reports on the assessment of lake problems and "clean lakes" strategy completed under the Statewide 208 Water Management Planning Program. A routine lake monitoring and assessment program should be developed by the IEPA and coordinated with various State, Federal, and local agencies. The program could be designed to incorporate LANDSAT MSS data. Completion of the multiyear data baseline for key Illinois lakes is desirable. Data collection could be coordinated with LANDSAT flyover. Water transparency and suspended particulates measurements should be emphasized.

A statistically significant number of lakes should be sampled during May-June and August-September to assess the range of lake quality and user impairments throughout the recreational season. Efforts should be made to extrapolate the contact-sensed data collected from these lakes to other significant Illinois lakes using LANDSAT technology. Water samples collected from a given lake and used in conjunction with LANDSAT data should be integrated from the surface down to the maximum depth sensed by the MSS (i.e., Secchi depth). The location and number of sampling sites should be governed, in part, by the spectral and spatial characteristics of the scanner. Summer is generally the best sampling period for Illinois lakes that are to serve as LANDSAT benchmark or reference water bodies. The lakes selected for calibration or modeling purposes should be representative of the range of lakes to be monitored and classified. This may require more lakes, and more types of lakes, than were used in this study. The Illinois EPA should consider classifying the larger Illinois reservoirs in a mapping or spatial context. Many of the larger water bodies are not homogeneous, and they exhibit substantial differences in water quality, both in the vertical and horizontal dimensions. The identification and location of such water types are of importance to lake management programs. On large water bodies, the MSS data should be calibrated against specific sample site information acquired through contact sensing. The use of LANDSAT MSS data as a means of identifying land cover and land use practices, and the relationship of land use to lake characteristics, should be examined.

When processing the LANDSAT MSS data, forward overlap as well as side overlap lake data should be extracted; this will provide better quality control. In addition, certain areas of the State should be defined as control points for the specific purpose of removing atmospheric effects from the MSS data.

The data acquired during a future recreational high-use season, the summer of 1977, the 1973 three-season National Euthrophication Survey (NES), and the fall of 1973 by LANDSAT should be evaluated, along with other information, to determine seasonal and long-term stability of the lake characteristics, to define, to identify, and to map the spatial-temporal distributions of lake quality, and to determine representative sample parameters, locations of sampling stations, and times for routine monitoring purposes.

Based upon analyses of the lake data base, the Illinois EPA should evaluate the lake assessment and the "clean lakes" strategy developed under the 208 program. Methods to control the sources of degradation causing fertility and sedimentation problems or management procedures to minimize adverse impacts should be determined for the lakes. Short-term remedial measures and long-range policies and programs should be assessed to maximize lake life span and usability by the public.

The applicability of using different multivariate approaches to ordinate and classify Illinois lentic water bodies should be further examined. For example, it may be inappropriate to reduce the number of contact-sensed parameters (as was done in this study) prior to the implementation of a segregation procedure designed to separate those lakes with sediment-related turbidity problems from those with turbidity problems related primarily to the presence of algae.

This project has successfully demonstrated that LANDSAT MSS data can be used to classify the lakes and artificial reservoirs of Illinois. It has served as the vehicle through which both Federal and State scientists, resource planners, and managers have developed a better understanding of the LANDSAT MSS's capabilities and limitations in the area of lacustrine trophic state assessment. The information relating to the technical aspects of the project (e.g., digital image-processing techniques, scanner specifications, multivariate statistical techniques) will largely appeal to the scientist. Resource managers and planners will find the cluster diagrams, lake rankings, and tabular lake data (including ancillary information) to be of practical use. Overall, the report should be of value in assisting the State of Illinois to meet its obligations under Public Law 92-500.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

A-space -- attribute space
C -- Celsius
CHLA -- chlorophyll *a*
CCT -- computer-compatible tape
CDC 3300 -- Control Data Corporation's Model 3300 digital computer
COMNET -- Computer Network Corporation, 5185 MacArthur Blvd N.W., Washington, D.C. 20016
COND -- conductivity
DN -- digital number
EPA -- U.S. Environmental Protection Agency
EROS -- U.S. Geological Survey's Earth Resources Observation System Data Center, Sioux Falls, South Dakota
FARINA -- image-processing software program designed to mask out corresponding spectral channels or bands
GRN -- green band, that portion of the spectrum between 500 and 600 nanometers, also known as band 4
GRNIR1 -- ratio of the green and near infrared-one band values
GRNIR2 -- ratio of the green and near infrared-two band values
GRNRED -- ratio of the green to red band values
GRNRK -- lake rank based on the LANDSAT MSS-measured green band value
ha -- hectare (1×10^4 square meters)
IBM 360 -- International Business Machines Model 360 digital computer
IDOC -- Illinois Department of Conservation
IEPA -- Illinois Environmental Protection Agency
IFOV -- instantaneous field of view
IPL -- Image Processing Laboratory
IR1 -- near infrared-one band, that portion of the spectrum between 700 and 800 nanometers, also called band 6
IR1IR2 -- ratio of the near infrared-one and near infrared-two band values
IR1RK -- lake rank based on the LANDSAT MSS-measured near infrared-one band value
IR2 -- near infrared-two band, that portion of the spectrum between 800 and 1,100 nanometers, also called LANDSAT band 7
IR2RK -- lake rank based on the LANDSAT MSS-measured near infrared-two value
ISEC -- inverse of Secchi depth transparency
JPL -- Jet Propulsion Laboratory, a NASA facility in Pasadena, California

LAKELOC -- Jet Propulsion Laboratory's interactive computer system for the extraction and analysis of water body images from LANDSAT and aircraft-acquired multispectral scanner computer-compatible tapes
LANDSAT -- Land satellite; e.g., LANDSAT-1, LANDSAT-3; satellites in NASA's Earth Resources Technology Satellite Program, formerly known as ERTS
LN -- natural logarithm; e.g., LNSEC is the natural logarithm transform of SEC
MSS -- LANDSAT multispectral scanner
NASA -- National Aeronautics and Space Administration
NES -- U.S. Environmental Protection Agency's National Eutrophication Survey Program
nm -- nanometer, 1×10^{-9} meters
PC1 -- generalized form of a multivariate trophic state index developed through principal component analysis of trophic state indicators
PC1F5 -- multivariate trophic state index derived through principal component analysis of the fall sampling round values of five indicators: Secchi depth, chlorophyll *a*, conductivity total phosphorus, and total organic nitrogen
PC1Y5 -- multivariate trophic state index derived through principal component analysis of the mean values for three sampling rounds of five indicators: Secchi depth, chlorophyll *a*, conductivity, total phosphorus, and total organic nitrogen
pixel -- picture element
r -- Pearson product-moment correlation coefficient
R -- multiple correlation coefficient
R^2 -- as used in regression, this is the square of the multiple correlation coefficient, also called the coefficient of multiple determination
r-matrix -- product-moment correlation matrix whose elements are used in principal components analysis
RAT100 -- LANDSAT spectral ratio
RED -- red band, that portion of the spectrum between 600 and 700 nanometers
REDIR1 -- ratio of the red and near infrared-one band values
REDIR2 -- ratio of the red and near infrared-two band values
REDRK -- lake rank based on the LANDSAT MSS-measured red band value
RTSGRN -- square root transformation of standardized LANDSAT green band values
SAHN -- sequential, agglomerative, hierarchic nonoverlapping
SAS -- Statistical Analysis System; a set of computer programs maintained by the SAS Institute, Inc., Post Office Box 10066, Raleigh, NC 27605
SCS -- scene color standard
SEC -- Secchi depth transparency
SGRN -- standardized form of the LANDSAT green band value
SIPS -- Statistical Interactive Programming System

SIR1 -- standardized form of the LANDSAT near infrared-one band value
SIR2 -- standardized form of the LANDSAT near infrared-two band value
SQRTSGRN -- square root of the LANDSAT standardized green band value
SRED -- standardized form of the LANDSAT red band value
STORET -- STOrage and RETrieval; EPA's computer-based water quality data bank
TON -- total organic nitrogen
TSS -- total suspended solids
TPHOS -- total phosphorus
VERTSLOG -- Jet Propulsion Laboratory's computer software program that performs digital image data format conversion and geometric conversion
VSS -- volatile suspended solids

SYMBOLS

$\wedge$ -- estimated value for a parameter; (e.g., TON: regression-derived estimate of total organic nitrogen)
$*$ -- multiplication, as used in computer programming
$**$ -- exponentiation, as used in computer programming
Δ_{jk} -- delta$_{(jk)}$, Euclidian distance between lake j and lake k
Δ^2 -- delta squared, squared Euclidian distance
3-D -- three-dimensional space

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SECTION 1

INTRODUCTION

BACKGROUND

Lakes and reservoirs have long been recognized as valuable resources serving as focal points for many types of recreational activity such as fishing, swimming, skiing, and boating. They also help to meet the water demands of municipalities, thermal-electric plants, commercial navigation, and irrigation projects. Many inland water bodies, particularly those in pristine condition, are valued for their aesthetic qualities. However, they also provide convenient places to dump the organic and inorganic wastes of society. Some are being drained to provide additional farmland; still others are encroached upon through landfill schemes. Many water bodies, particularly those in agricultural areas and in or near population centers, are exhibiting the secondary effects of man-induced eutrophication (e.g., nuisance algal blooms).

Eutrophication -- the process of nutrient enrichment of water -- occurs both naturally and as a consequence of man's activities. Many of man's approaches to the disposition of municipal sewage and industrial wastes, along with his land-use practices, impose large nutrient loads on lakes and reservoirs. This enrichment process may result in algal blooms and other secondary effects of eutrophication and thereby make these water bodies less attractive to users. In Illinois, significant impacts on lake water quality and user preference are frequently associated with sediment pollution in the water bodies.

The rational management of a State's or the Nation's inland lentic resources requires, as an initial step, that an inventory be made that focuses on geographic, morphometric, biotic, and physiochemical factors characterizing these waters. Thus, in 1972, the U.S. Congress, responding to citizens and organizations concerned with the decline in the quality of the Nation's water resources, passed Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972. The legislation requires that each State identify and classify, according to trophic condition, all publicly owned freshwater lakes under its jurisdiction (Sections 106 and 314).

For States with large numbers of lakes and artificial reservoirs, the mandated task is one of major proportions. The State of Illinois, for example, has over 80,000 impoundments (2,700 of which have surface areas of 2.4 hectares or more and are classified as lakes by the Illinois Department of Conservation), and collecting the data necessary for identification and classification entails a project of sizable logistical and monetary proportions. The fielding of boat-equipped crews is hindered by budgetary, manpower, and time constraints. The use of helicopter-borne field crews, although attractive, is beyond the financial budget of the State.

The aforementioned circumstances dictate that consideration be extended to other than traditional approaches when attempting to trophically classify large numbers of water bodies. Any such approach should be cost effective and rapid and should yield results having practical value. One such approach employs data collected by satellite-borne sensors to develop trophic classifications of water bodies.

On July 23, 1972, the National Aeronautics and Space Administration (NASA) inserted a satellite called LANDSAT-1 (Figure 1) into a sun-synchronous near-polar orbit to monitor the earth's resources. A companion satellite, LANDSAT-2, was successfully launched January 22, 1975. The tandem satellites provide repetitive coverage of nearly every point on the earth's surface on a 9-day basis. A third satellite, LANDSAT-C and now known as LANDSAT-3, was successfully launched March 5, 1978. The operation of the LANDSAT-1 multispectral scanner ceased on January 6, 1978. Several types of instrumentation are carried by the satellites including an imaging multispectral scanner (MSS). Numerous investigations (e.g., Blackwell and Boland 1979, Yarger and McCauley 1975, Moore and Haertel 1975, Strong 1973, Fisher and Scarpace 1975, Boland and Blackwell 1975, Boland and Blackwell 1978, Boland 1976, Rogers et al. 1976, Rogers 1977) have demonstrated the potential capabilities of the LANDSAT MSS for lake monitoring and classification when used in combination with contact-sensed data.

OBJECTIVES

The basic objective of this project is to classify Illinois lakes and reservoirs as to their trophic status and other characteristics, using an approach combining contact-sensed and remotely sensed (i.e., LANDSAT MSS) data. Classification, in a restricted sense, is the procedure of placing n objects or p attributes into groups as defined by certain decision criteria. A broader definition of classification includes the process of ordination and its resultant products. In this report, classification is used in its less restrictive sense.

Specific project objectives are to:

1. Develop rankings for some 150 Illinois lakes and artificial reservoirs based on estimated magnitudes of the following trophic indicators:
    a. Secchi disc transparency (SEC);
    b. Chlorophyll a (CHLA);
    c. Total organic nitrogen (TON); and
    d. Total phosphorus (TPHOS).
2. Develop lake rankings based on multivariate trophic indices.
3. Compile lake surface area estimates.
4. Identify lake trophic classes and their quality.

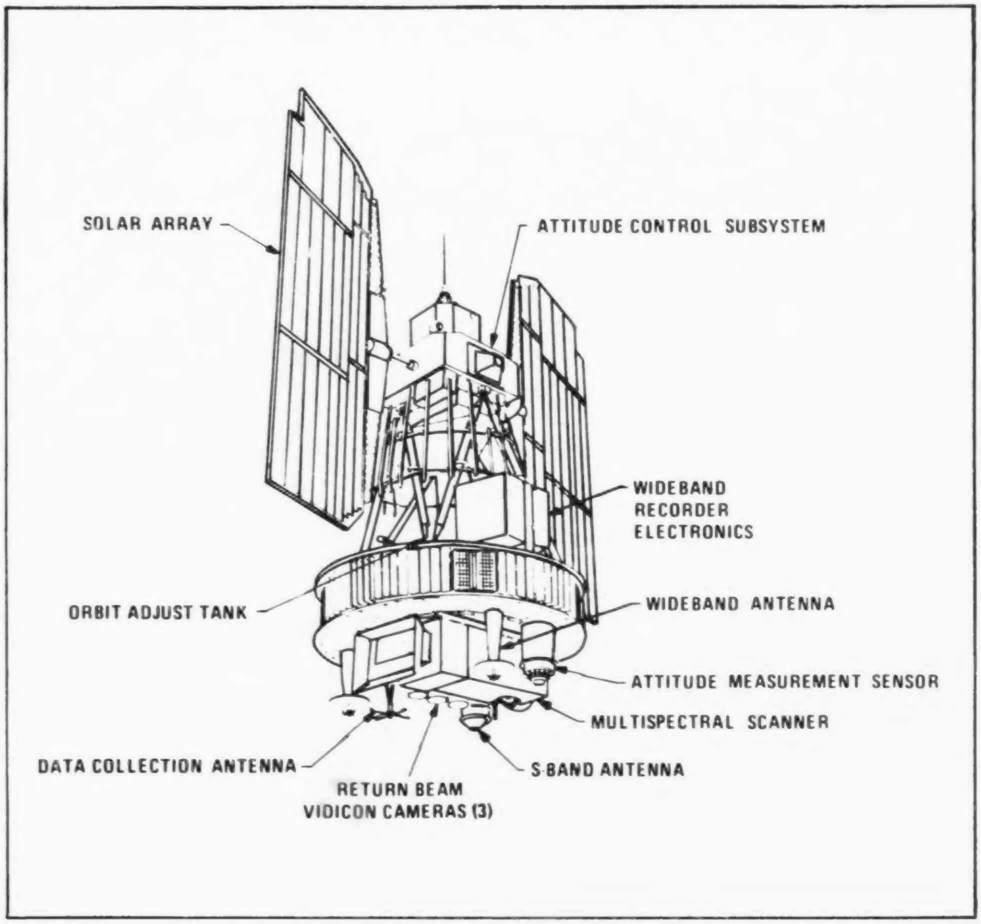
SOLAR ARRAY
ATTITUDE CONTROL SUBSYSTEM
WIDEBAND RECORDER ELECTRONICS
ORBIT ADJUST TANK
WIDEBAND ANTENNA
ATTITUDE MEASUREMENT SENSOR
MULTISPECTRAL SCANNER
DATA COLLECTION ANTENNA
S-BAND ANTENNA
RETURN BEAM VIDICON CAMERAS (3)

Figure 1. NASA's LANDSAT space observatory (NASA 1972).

5. Develop procedures to classify Illinois water bodies into groups with similar qualities and to rank the groups in order of quality.
6. Identify the parameters that most significantly affect lake quality and use.

SECTION 2

CONCLUSIONS

The analyses of LANDSAT multispectral scanner (MSS) and near-concurrent contact-sensed data, and ancillary information, for 145 Illinois water bodies indicate that:

1. Lake clusters can be derived from LANDSAT MSS raw data and MSS-estimated trophic indicator values; the clusters compare well with near-concurrent contact-sensed data and ancillary information. The application of an unsupervised clustering algorithm to raw MSS data resulted in the establishment of distinctive lake clusters and subclusters, each identifiable in terms of general water quality, use impairment, and lake characteristics.

2. LANDSAT MSS data can be used with contact-sensed data to develop regression models that provide relative estimates of Secchi depth, chlorophyll a, total organic nitrogen, total phosphorus, and two multivariate trophic state indices. Though less accurate and precise than contact-sensed trophic indicator values, the LANDSAT-derived parameter estimates can be used to develop generalized rankings of Illinois lakes.

3. Regression models developed from MSS and contact-sensed data for lakes with large parameter value ranges and minimal contact-sensed data were more effective for the Illinois lakes studied when spectral ranks rather than normalized spectral data were used. Parameter estimation models obtained from raw MSS data were least reliable.

4. LANDSAT spectral index signatures developed from raw MSS data provide an acceptable characterization of general lake quality and use impairment and can be used to establish an objective assessment baseline for lake ordination and inventory purposes.

5. The LANDSAT MSS provided surface area estimates generally within 10 percent of values derived from State of Illinois data files for the study lakes. In other geographic areas, LANDSAT-derived lake surface area estimates have exhibited excellent correspondence with area estimates derived from concurrently acquired aerial photography; such imagery was not available for use in this project.

6. The LANDSAT MSS is an economically viable tool for the acquisition, within three days and at a spatial resolution of about 0.64

hectares, of data from all Illinois lakes and artificial reservoirs of significant areal extent (i.e., four or more hectares).

7. The extraction and processing of lake MSS data is effectively accomplished, with respect to both cost and time, through the use of LAKELOC, a recently developed image-processing system.

8. Lacustrine water quality and use impairment in Illinois is significantly impacted by suspended particulate matter. Lake morphology and hydraulic factors affect the suspensoid load and general water characteristics.

9. The best quality lakes studied were generally deep, for Illinois, with long retention periods (one year or more). Water quality and general use potential decreased for shorter retention-time lakes with shallower depths; generally the upper portions of reservoirs (areas of major stream inflow) exhibit increased use impairment.

10. Although all of the study lakes are affected by high levels of phosphorus, overall water quality is basically influenced by the effect of suspended particles on water transparency.

SECTION 3

RECOMMENDATIONS

Most of the problems encountered during this study were successfully addressed. From the perspective of the State, this project was highly successful, both in the insights that were gained while addressing these problems and in the development of a high quality, comprehensive, objective, short-term data base on Illinois lakes. The following recommendations are made in light of the study results and are consistent with reports on the assessment of lake problems and "clean lakes" strategy completed under the Statewide 208 Water Management Planning Program (IEPA 1978a, IEPA 1978b).

1. A routine lake monitoring and assessment program should be developed by the Illinois Environmental Protection Agency (IEPA) and coordinated with various State, Federal, and local agencies. The program could be designed to incorporate LANDSAT multispectral scanner (MSS) data.

2. Completion of the multiyear data baseline for key Illinois lakes is desirable. A significant number of lakes should be sampled during May-June and August-September to assess the range of lake quality and user impairments throughout the recreational season. Data collection could be coordinated with LANDSAT flyover. Water transparency and suspended particulates measurements should be emphasized.

3. Efforts should be made to extrapolate the contact-sensed data described in the second recommendation to significant Illinois lakes using LANDSAT technology.

4. The data acquired during a future recreational high-use season, the summer of 1977, the 1973 three-season National Eutrophication Survey (NES), and the fall of 1973 by LANDSAT should be evaluated, along with other information, to determine seasonal and long-term stability of the lake characteristics; to define, identify, and map the spatial-temporal distributions of lake quality, and to determine representative sample parameters, locations of sampling stations, and times for routine monitoring purposes.

5. Based upon analyses of the lake data base, the Illinois EPA should evaluate the lake assessment and the "clean lakes" strategy developed under the 208 program. Methods to control the source(s) of degradation causing fertility and sedimentation problems or

management procedures to minimize adverse impacts should be determined for the lakes. Short-term remedial measures and long-range policies and programs should be assessed to maximize lake lifespan and usability by the public.

6. Water samples collected from a given lake and used in support of LANDSAT should be integrated from the surface down to the maximum depth sensed by the MSS (i.e., Secchi depth). The location and number of sampling sites should be governed, in part, by the spectral and spatial characteristics of the scanner. Summer is generally the best sampling period for Illinois lakes that are to serve as LANDSAT benchmark or reference water bodies.

7. The lakes selected for calibration or modeling puposes should be representative of the range of lakes to be monitored and classified. This may require more lakes, and additional types of lakes, than were used in this study.

8. The Illinois EPA should consider classifying the larger Illinois reservoirs in a mapping or spatial context. Many of the larger water bodies are not homogeneous, and they exhibit substantial differences in water quality, both in the vertical and horizontal dimensions. The identification and location of such water types is of importance to lake management programs. On large water bodies, the MSS data should be calibrated against specific sample site information acquired through contact sensing.

9. The use of LANDSAT MSS data as a means of identifying land cover and land-use practices and their relationship to lake characteristics should be examined.

10. When processing the LANDSAT MSS data, forward overlap as well as side overlap lake data should be extracted; this will provide better quality control.

11. Certain areas of the State should be defined as control points for the specific purpose of removing atmospheric effects from the MSS data.

12. The applicability of using different multivariate approaches to ordinate and classify Illinois lentic water bodies should be further examined. For example, it may be inappropriate to reduce the number of contact-sensed parameters (as was done in this study) prior to the implementation of a segregation procedure designed to separate those lakes with sediment-related turbidity problems from those with turbidity problems related primarily to the presence of algae.

SECTION 4

GEOGRAPHY AND LAKES OF ILLINOIS

GEOGRAPHY

An overview of Illinois physical geography is provided in this subsection. More detailed descriptions can be found elsewhere (e.g., Strahler 1969, Fenneman 1938, Thornbury 1965). The information presented in the following subsections draws heavily from the work of the State of Illinois Environmental Protection Agency (IEPA 1976).

Physiography and Geology

Illinois is largely a low prairie plain with an average elevation of approximately 193 meters above sea level (Kofoid 1903 as cited by Gunning 1966). With an elevation of 377 meters, Charles Mound, located in the northwestern corner of the State near the Illinois-Wisconsin border, is the highest topographic point (Rand McNally 1971). [Gunning (1966) reports an elevation of 383 meters. Bethel (1969) records 378 meters as the elevation of Charles Mound.] The lowest point in the State is at Cairo where the low-water mark of the Ohio River has been measured as 82 meters (Gunning 1966). Local relief, the difference in elevation between lowest and highest topographic points in adjacent locations, is typically less than 60 meters (IEPA 1976). Fenneman (1928) has divided the State into four physiographic provinces (Figure 2). Leighton et al. (1948) have further subdivided Illinois into eight physiographic sections using the following criteria: bedrock topography, extent of the several glaciations, glacial morphology differences, age differences of the uppermost drift, height of the glacial plain above the main lines of drainage, glaciofluvial aggradation of basin areas, and glaciolacustrine action.

More than 90 percent of Illinois is located in the Central Lowland province. With the exception of the Wisconsin Driftless section located in extreme northwestern Illinois (Jo Daviess and Carroll Counties), all of the province has been glaciated. The Ozark Plateaus, Interior Low Plateaus, and Coastal Plain province account for the remainder of Illinois.

Three sections constitute the bulk of the Central Lowland province in Illinois: the Great Lakes section, the Wisconsin Driftless section, and the Till Plains section. The Great Lakes section, located in northeastern Illinois, is largely dominated by an area called the Wheaton morainal country. Wedged between the morainic area and Lake Michigan is the Chicago lake plain. The lake plain is characterized by a flat surface underlain largely by till (a heterogeneous mixture of rock fragments ranging in size

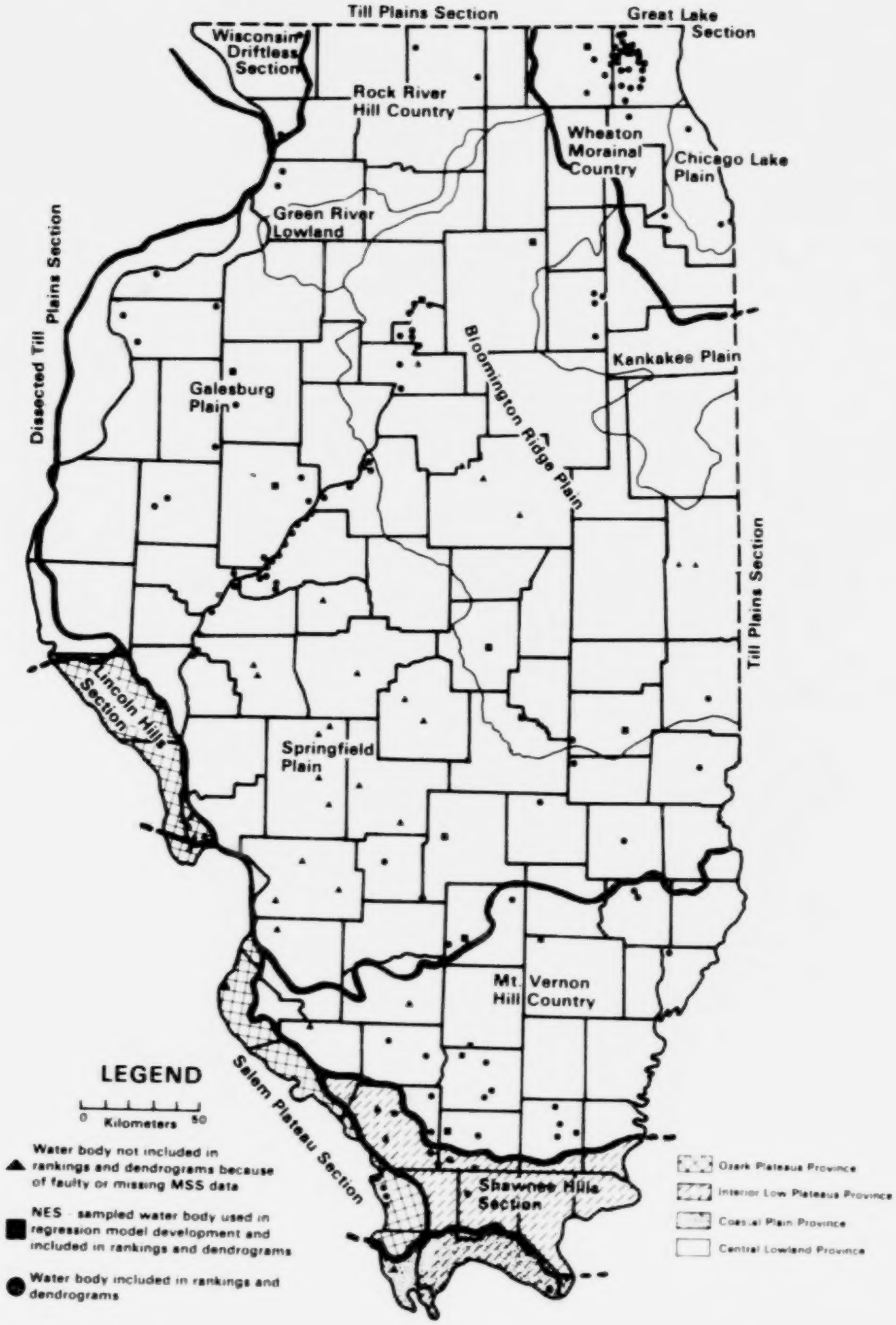
Till Plains Section
Great Lake Section
Wisconsin Driftless Section
Rock River Hill Country
Wheaton Morainal Country
Chicago Lake Plain
Green River Lowland
Dissected Till Plains Section
Kankakee Plain
Galesburg Plain
Bloomington Ridge Plain
Till Plains Section
Lincoln Hills Section
Springfield Plain
Mt. Vernon Hill Country
Salem Plateau Section
Shawnee Hills Section
LEGEND
0 Kilometers 50
▲ Water body not included in rankings and dendrograms because of faulty or missing MSS data
■ NES - sampled water body used in regression model development and included in rankings and dendrograms
● Water body included in rankings and dendrograms
Ozark Plateaus Province
Interior Low Plateaus Province
Coastal Plain Province
Central Lowland Province

Figure 2. Physiographic provinces of Illinois. The water bodies marked on the map were proposed for inclusion in this project. Figure adapted from Illinois State Geological Survey map (IEPA 1976).

from clay to boulders and associated with glaciers) and having a gentle slope toward Lake Michigan. Postglacial erosion has been of a relatively small magnitude and is most evident in the valleys along the Fox and Des Plaines Rivers (IEPA 1976).

The topography of the Wisconsin Driftless section (Figure 2) reflects the physical-chemical character of the underlying rock and is a consequence of the apparent lack of glacial activity in the area. Dendritic drainage systems, tributary to the Mississippi River, dissect the section. A substantial amount of drainage occurs through small caves and solution channels. However, features associated with karst topography are not readily evident.

Approximately 80 percent of the State is classified as belonging to the Till Plains section, an area dominated by broad till plains with poorly developed drainage systems. The western and southern limits of the Bloomington ridged plain effectively define the boundary separating the older Illinoian deposits from those Wisconsinian in age. Physiographic contrasts (e.g., degree of drainage integration, extent of soil development, erosional modification of the topography) have developed because of these age differences.

A fourth section of the Central Lowland province, the Dissected Till Plains section, is found in three western Illinois counties, Hancock, Adams, and Pike. In this section glaciation occurred in an earlier stage, the Kansan, and this accounts for the submaturely dissected landscape (Fenneman 1938). The longer time element has allowed the Dissected Till Plains section to reach a more advanced point in the postglacial erosion cycle than the Till Plains section to the east (Fenneman 1938).

The Ozark Plateaus province is represented in Illinois by two sections, the Lincoln Hills section and the Salem Plateau section. Both sections are found along the southwestern boundry of the State (Figure 2). The sole representative of the Interior Low Plateaus province in Illinois is the Shawnee Hills section (also known as the Shawnee section) found in the southern portion of the State. The southern tip of Illinois lies in the Mississippi Alluvial Plain section (commonly called the Mississippi Embayment) of the Coastal Plain province. Detailed descriptions of these relatively minor components of Illinois physiography can be found in Fenneman (1938) and Thornbury (1965).

The geologic units of Illinois are classified into four major divisions: 1) Precambrian basement rock; 2) consolidated sedimentary bedrock; 3) a variably thick blanket of glacial drift; and 4) a mantle of loess. The Precambrian basement rock lies hidden, covered by some 600 to more than 3,960 meters of sedimentary strata. Borings, both in Illinois and immediately outside the State's border, have yielded plutonic and volcanic rocks of granitic or closely related composition (Bradbury and Atherton 1965).

Consolidated sedimentary rocks, ranging in age from Cambrian through Tertiary, are found throughout the State. Extensive exposures of these rocks are limited to extreme northwestern Illinois and to the southwestern and southern part of the State in areas along the Mississippi and Ohio Rivers falling outside the glacial margin. Scattered bedrock outcrops, usually limited to areas of high bedrock or the walls of the more deeply cut valleys, are found within the glaciated region. The Ordovician and Silurian rocks are largely dolomite. The Mississippian rocks are dominated by limestone, and the Pennsylvanian rocks by shale and sandstone. Illinois is noted for its large deposits of mineable coal, which are found in the Pennsylvanian strata.

Approximately 90 percent of Illinois is blanketed by glacial deposits consisting of both stratified drift and till deposited during each of the four major glacial stages (Figure 3). Drift of Nebraskan age, the first glacial stage, is known in Illinois only from subsurface deposits in the western part of the State. The Kansan glaciation covered most of the State, but subsequent glacial stages have restricted exposed Kansan tills to a small area in western Illinois, the Dissected Till Plains section. The third glaciation, the Illinoian, marked the southern most incursion of the continental ice sheet in North America. The ice extended to within 33 kilometers of the Mississippi Embayment in southernmost Illinois, laying down an extensive blanket of drift over much of the State. The last glaciation, the Wisconsinian, is recognized as a major factor in molding the character of the modern landscape (Flemal 1972). The Wisconsinian deposits, largely confined to northeastern Illinois, have not been exposed to weathering as long as the older Illinoian deposits and, therefore, exhibit marked soil differences when compared to Illinoian-derived soils.

Willman and Frye (1970) report that as much as half of the material comprising the tills of Illinois has been transported less than 160 kilometers from its bedrock source. The glacial drift ranges in thickness from zero to about 180 meters, with the average being about 30 meters. Relatively thin layers of drift are found in western and southern Illinois. The northeastern quarter of the State is mantled by a thick drift deposit. As might be expected, extremely thick drifts blanket the major bedrock valleys.

Much of Illinois is covered by loess, a silty windblown deposit that consists chiefly of dust from dry glacial river valley floors. It is thickest east of the valleys because of the prevailing westerly winds. It becomes progressively thinner as the distance from the source increases. Loess, the most extensive parent material of Illinois soils, varies in average thickness from about 2 to 6 meters in western Illinois to 0.5 to 1.5 meters in the eastern part of the State. The Army Corps of Engineers (1969) reports it as being the major constituent of the suspended sediment transported in Illinois streams. The State's loess-covered plains are widely recognized for their agricultural productivity.

Soils

The major parent materials forming Illinois soils are loess, outwash, till, and alluvium. Bedrock and accumulations of organic material (e.g., peat) are of relatively minor importance. The following is a reiteration of IEPA's (1976) description of Illinois soils, which in turn is based largely on the work of Fehrenbacher et al. (1967).

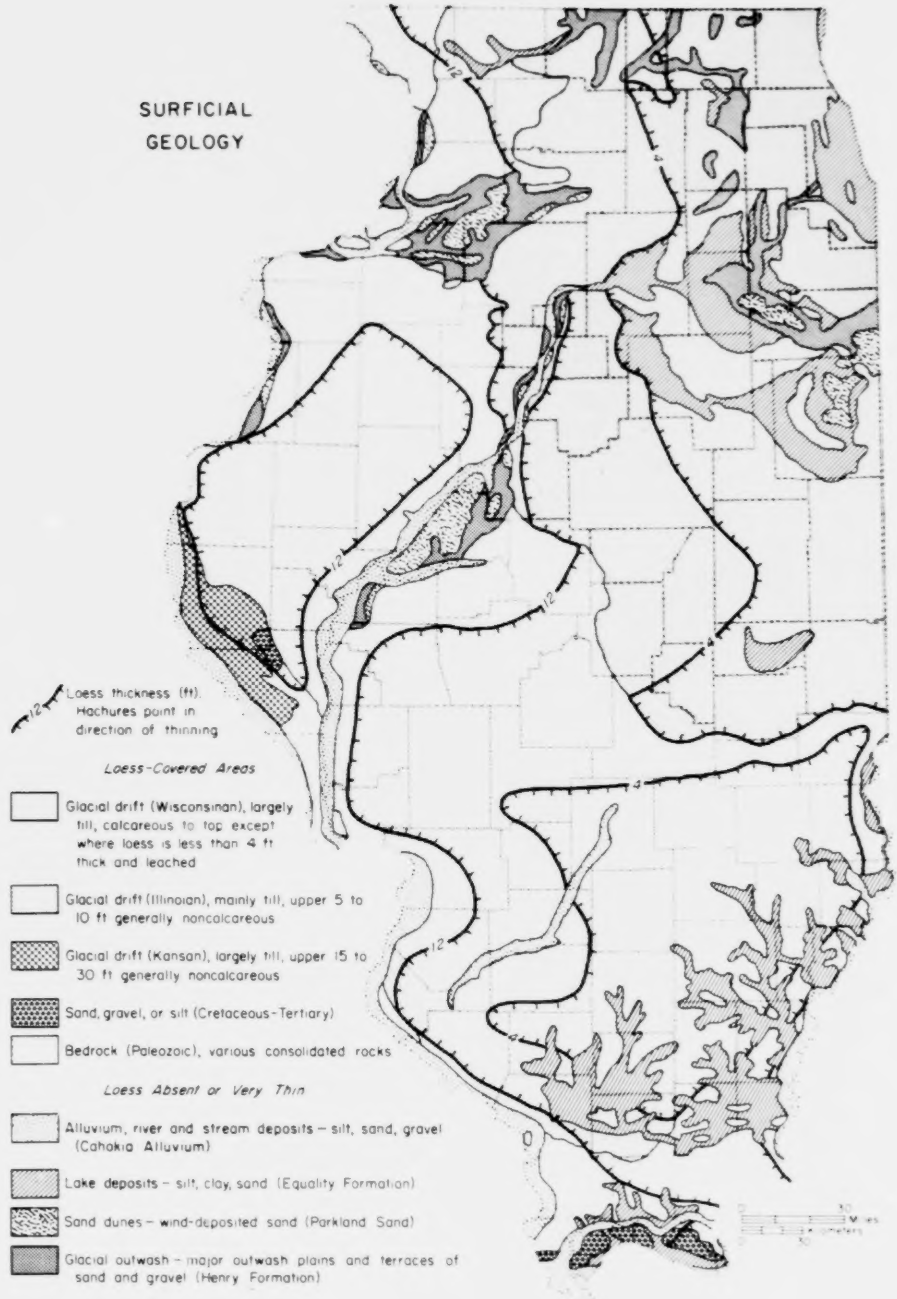
SURFICIAL GEOLOGY
12
Loess thickness (ft). Hachures point in direction of thinning
Loess-Covered Areas
Glacial drift (Wisconsinan), largely till, calcareous to top except where loess is less than 4 ft thick and leached
Glacial drift (Illinoian), mainly till, upper 5 to 10 ft generally noncalcareous
Glacial drift (Kansan), largely till, upper 15 to 30 ft generally noncalcareous
Sand, gravel, or silt (Cretaceous-Tertiary)
Bedrock (Paleozoic), various consolidated rocks
Loess Absent or Very Thin
Alluvium, river and stream deposits – silt, sand, gravel (Cahokia Alluvium)
Lake deposits – silt, clay, sand (Equality Formation)
Sand dunes – wind-deposited sand (Parkland Sand)
Glacial outwash – major outwash plains and terraces of sand and gravel (Henry Formation)
4
0
Miles
Kilometers
30

Figure 3. Generalized surficial geology of Illinois. In uneroded areas the loess thins from 25 to 100 feet thick in the bluffs of the major valleys to 1 to 2 feet in areas farthest from the valleys. (Figure courtesy of the Illinois State Geological Survey.)

Of the 10 major soil orders comprising the 7th Approximation (Soil Survey Staff 1960) -- Aridisols, Vertisols, Spodosols, Ultisols, Oxisols, Histosols, Inceptisols, Mollisols, Alfisols, Entisols -- the latter three dominate Illinois (Figure 4).

Histosols occur mainly in extreme northeastern Illinois. They are organic soils (peats and mucks) that are distinguishable from those of the other nine orders by gross composition differences, most notably their high organic content of 20 percent or better (Simonson 1962). Histosols are wet soils, generally requiring drainage when used for most agricultural purposes.

Alfisols predominate in southern Illinois. A light color is generally associated with the surface layer; if the color is dark, the surface layer is less than 25 centimeters thick. In either case the surface layer has an organic content of less than one percent throughout its total thickness. Another characteristic of Alfisols is a recognizable B horizon of clay accumulation.

Mollisols cover about 49 percent of the State with most occurring in central and northern Illinois. These are mineral soils possessing what is called a mollic epipedon. This darkened surface layer has an organic content of more than one percent, is high in base saturation, and is friable.

Inceptisols are usually found in small or narrow areas and are included with Mollisols in the bottom lands and with the Alfisols in the uplands. Although lacking the mollic epipedon of the Mollisols and the B horizon of clay accumulation associated with Alfisols, Inceptisols do have recognizable horizons or show evidence of the beginning of horizon development.

Entisols are mineral soils whose profiles contain few and faint horizons. They cover an estimated 1.5 percent of Illinois, occurring along streams and in very sandy areas. Entisols are known to form in regoliths consisting of highly resistant minerals, in areas where the accumulation of surface materials keeps pace with horizon differentiation, and in localities where the erosion rate keeps up with horizon differentiation (Simonson 1962).

Climate

According to the Koppen-Geiger system of climate classification, the northern third of Illinois is classified as humid continental; the remainder of the State is placed in the humid subtropical category (Strahler 1969). The State's geographic location results in great variations in temperature and precipitation over the course of a given year. The mean annual temperature is about 8 degrees Celsius (°C) in the north, increasing to 15°C in the south. Normally, January is the coldest month with a mean temperature of about -6°C in the north and 2°C in the south. July, usually the hottest month, exhibits a similar north to south temperature trend with the mean values being about 23°C and 27°C, respectively. Mean annual precipitation also displays a north-to-south trend -- 80 centimeters and 120 centimeters, respectively. Except for a small area in the southern part of Illinois, the period of maximum precipitation occurs during the

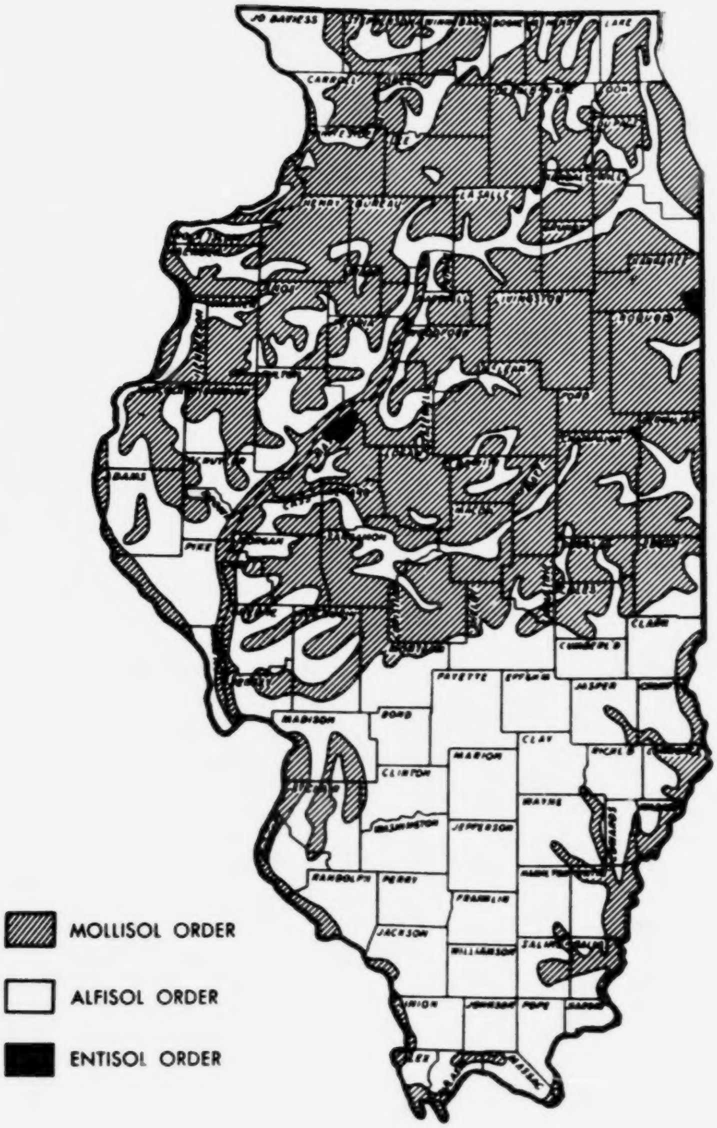
MOLLISOL ORDER
ALFISOL ORDER
ENTISOL ORDER
JO DAVIESS
LAKE
PIKE
ADAMS
MADISON
BOND
FAYETTE
JASPER
CLAY
MARION
CLINTON
WAYNE
JEFFERSON
RANDOLPH
PERRY
FRANKLIN
JACKSON
WILLIAMSON
JOHNSON
POPE
CLARK

Figure 4. Major soil orders in Illinois (from Fehrenbacher et al. 1967). Of the 10 soil orders in the 7th Approximation, five -- Mollisols, Alfisols, Entisols, Histosols, and Inceptisols -- are important in Illinois. The Inceptisols and Histosols cover relatively small areas and are not shown in the above figure.

growing season. In general, northern Illinois receives a larger percentage of its total precipitation during the growing season than does the southern part. This is important because it tends to make the lesser precipitation in the north as effective for growing crops as the greater annual quantities in southern Illinois (Page 1949).

Drainage

Three major rivers border Illinois: the Mississippi on the west, the Ohio on the south, and the Wabash on the southeast (Figure 5). Large streams that provide the internal drainage of the State include the Illinois, Rock, Kaskaskia, Big Muddy, Embarras, and Little Wabash Rivers. The Illinois River, the largest stream within Illinois, drains the State in a generally southwesterly direction. The Rock River, the second largest stream in the State, drains the northwestern portion of Illinois as well as parts of adjacent southern Wisconsin. Three major sub basins -- the Pecatonica, Kishwaukee, and Green River Basins -- comprise the Rock River Basin.

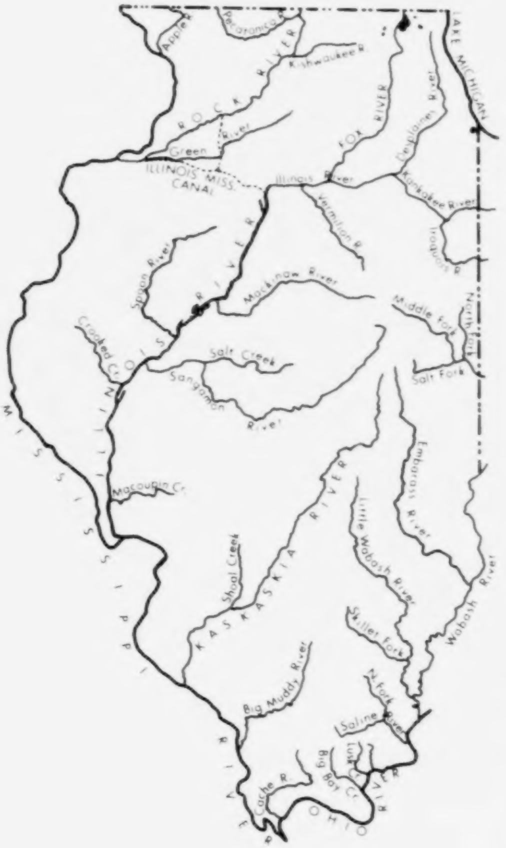
Apple R.
Pecatonica R.
Kishwaukee R.
ROCK RIVER
Green River
ILLINOIS MISS. CANAL
Illinois River
FOX RIVER
Desplaines River
LAKE MICHIGAN
Kankakee River
Iroquois R.
Vermilion R.
Spoon River
ILLINOIS RIVER
Mackinaw River
Crooked Cr.
Middle Fork
North Fork
Salt Creek
Sangamon River
Salt Fork
MISSISSIPPI RIVER
Macoupin Cr.
Embarrass River
KASKASKIA RIVER
Little Wabash River
Shoal Creek
Wabash River
Skillet Fork
Big Muddy River
N. Fork
Saline River
Cache R.
Big Bay Cr.
OHIO RIVER

Figure 5. Principal streams of Illinois (from O'Donnell 1935).

The Kaskaskia and Big Muddy Rivers join the Mississippi River in southwestern Illinois. The Kaskaskia, the larger of the two, originates in east-central Illinois. The Big Muddy River is confined to the southern portion of the State. Four Illinois streams, the Embarras, Little Wabash, Vermilion-Wabash, and Saline, all flow in generally southeasterly courses and feed the Ohio and Wabash Rivers.

Approximately 81 percent of Illinois is drained directly to the Mississippi River by means of southwest flowing streams (e.g., Illinois and Rock Rivers). Almost 19 percent is drained indirectly to the Mississippi River by way of the Ohio and Wabash Rivers. Less than 0.1 percent of the State's area is drained into the Great Lakes system (McCarthy 1972).

Land Use

Illinois covers an area of approximately 146,076 square kilometers (14,607,600 hectares), not including the 3,950 square kilometers of Lake Michigan. The actual land area has been calculated as 144,872 square kilometers (Bethel 1969). Eighty-three percent of Illinois human population is classified as urban with about 80 percent being clustered into 10 Standard Metropolitan Statistical Areas (SMSA).

Agriculture is the dominant land use in Illinois, with tilled crops dominating. Cropland distribution is more dense in the central and northern parts of the State than in the western and southern parts. The Illinois Cooperative Crop Reporting Service (1974) found the major crop to be soybeans, followed in order by corn, wheat, and hay. IEPA (1976) report that about 74 percent of the inventoried land is devoted to tilled crops; cropland increased from 96,620 square kilometers in the 1958 inventory to 98,745 square kilometers in 1967. Inventoried land is defined as the total surface area of the State minus Federally owned land, water areas, and land used for urban purposes. The inventory was conducted by the Illinois Inventory of Soil and Water Conservation Needs to determine the use and condition of privately owned rural land in Illinois. Inventory participants included the United States Department of Agriculture and various State agencies.

Inventoried woodlands and forests cover approximately 11 percent of Illinois, with most being classified commercial. The noncommercial forests serve very important recreational and conservation functions. Forest lands have declined from 1958 to 1967 as indicated by the area estimates of 15,783 and 14,569 square kilometers, respectively.

The third largest use of rural land is grazing. Approximately 10 percent of the inventoried land is used to pasture livestock. A slight expansion in pasturage has been noted, with 13,395 square kilometers reported for 1958 and 13,557 square kilometers for 1967. Grazing lands, generally confined to the more hilly regions, are most dense in northwestern, western, and southern Illinois.

Another land-use category, "other land" (rural land that is not used as cropland, forest land, or pastureland), has declined from 7,284 square kilometers in 1958 to 6,070 square kilometers in 1967. Some "other land" is used for recreation and wildlife. In some localities the quarrying of sand and gravel and the mining of coal are of major importance. The extraction of sand and gravel occurs mainly near major urban centers (e.g., Chicago). Illinois, the fourth-ranked State in coal production (IEPA 1976), has large coal deposits in its bedrock of Pennsylvanian age. Coal strip mines are found along the outcrop margins of Pennsylvanian strata. Elsewhere, the depth of the coal from the surface necessitates the use of underground mining.

LAKES OF ILLINOIS

There is far from universal agreement as to what constitutes a lake. Veatch and Humphrys (1966) suggested that to give the word "lake" a precise, limited meaning would probably be an exercise in futility because the word has been in use for a long time in a variety of applications. The word is used as a synonym for pond, reservoir, and sea. It has been applied to bodies of fresh water and saline water, to standing water and widenings in rivers, to bodies of water measuring less than a hectare and to those gauged in hundreds of thousands of hectares, to naturally occurring water bodies and manmade reservoirs, to water-filled or partially filled basins, and to basins void of water. "Lake" is generally more prestigious than other common names (e.g., pond, slough, reservoir) and is preferred by promoters of water-based tourist and recreational businesses and commercial developers of shoreline property (Veatch and Humphrys 1966). Nevertheless, numerous attempts have been made to define and delimit the members of lentic series (i.e., lake, pond, marsh, and their intergrades).

Forel defined a lake as a body of standing water occupying a basin and lacking continuity with the sea, and a pond as a lake of slight depth (Welch 1952). Welch defined a lake as a "... body of standing water completely isolated from the sea and having an area of open, relatively deep water sufficiently large to produce somewhere on its periphery a barren, wave-swept shore." He employed the term "pond" "... for that class of very small, very shallow bodies of standing water in which quiet water and extensive occupancy by higher aquatic plants are common characteristics ..." and suggested that all larger bodies of standing water be referred to as lakes. Zumberge (1952) defined a lake as an inland basin filled with water. Harding (1942) described lakes as "... bodies of water filling depressions in the earth's surface." The Illinois Department of Conservation (IDOC) uses a size criterion (2.4 hectare or larger in surface area) to define lake. In this report no deliberate effort will be made to carefully distinguish a lake from another lentic body on the basis of a definition. We are using the term lake in its broadest sense. For example an artificial reservoir may be called a lake or, at times, a water body.

The Illinois Surface Water Inventory prepared by the State of Illinois Department of Conservation (1972) reported that the State had 2,706 lakes (2.4 ha or larger in surface area) and 73,595 ponds (less than 2.4 ha in surface area) in 1972. Of the 2,706 lakes, only 709 were natural -- either glacial lakes in the north or flood plain or oxbow lakes along the major rivers. The remaining 1,997 were manmade (IDOC 1972, Gunning 1966, and

Bennett 1960). An inventory of Illinois lakes (IEPA 1975) reveals a total of 773 publicly owned freshwater lakes, with 273 lakes having surface areas in excess of 8 hectares. Excluding the portion of Lake Michigan within the Illinois boundary, the total area of publicly-owned freshwater lakes is 58,818 hectares (IEPA 1975).

Illinois lacks pristine lakes such as those found in northern Minnesota and Wisconsin. Illinois lakes, however, exhibit a range of morphologic, water quality and usability characteristics. Table 1 lists brief comments regarding lake types in Illinois.

Lake Succession

Lakes, although giving the impression of permanence when measured on the scale of the human lifespan, are transitory features of the earth's surface. Most lakes, regardless of their origin, pass through the process of ecological succession that ultimately results in a terrestrial environment. The ephemeral nature of natural lakes is a consequence of two fundamental processes -- the downcutting of the outlet and, more importantly, the deposition of allochthonous and autochthonous materials in the basin. While downcutting of the outlet is of little consequence to Illinois artificial lakes and reservoirs, loss of depth and capacity occurs because of sediments delivered by streams and from bank erosion.

Many lakes (presumably) commence the successional process as bodies possessing relatively low concentrations of nutrients and, generally, low levels of productivity. Edmondson (1974) suggested that the idea that all lakes are born oligotrophic and gradually become eutrophic as they age is an old misconception. The importation and deposition of materials (e.g., sediment) from the shoreline and the surrounding watershed gradually decreases the lake depth. The addition of allochthonous materials normally enriches the water and thereby stimulates the production of autochthonous organic materials. Autochthonous materials increase the sedimentation rate and accelerate succession. Marked floral and faunal changes occur. Algal blooms become more common along with submergent and, eventually, emergent aquatic macrophytes. Desirable game fish may be replaced by less desirable species, the so-called rough fish. A lake eventually becomes a marsh or swamp that, in turn, terminates as dry land.

Lindeman (1942) stressed the productivity aspects in relation to lake succession. Figure 6 represents the probable successional productivity relationships for a hypothetical hydrosere developing from a moderately deep lake located in a fertile humid continental region. Productivity is initially low, a consequence of low nutrient levels, but increases rapidly as nutrients become more available. The length of time required for completion of the successional process is a function of several factors including lake basin morphology, climate, and the rate of influx and nutrient value of allochthonous materials. It is readily apparent that allochthonous nutrients can drastically increase lake productivity and thereby shorten the lifespan of a lake.

TABLE 1. DESCRIPTION OF LAKE TYPES IN ILLINOIS

Parameter	Natural Lakes		
	Glacial		Backwater
	Normal	Flowage	
Location	Limited to northeastern Illinois including Cook, Lake, and McHenry Counties.	Northeastern Illinois, particularly the Fox Chain of Lakes.	Along major streams including the Illinois, Mississippi, and Ohio Rivers.
Physical/morphological characteristic	Small (most are less than 80 ha). Long retention time. Location of maximum depth is highly variable. Shoreline tends to be regular while the basin is cone shaped. Very long life expectancy, a consequence of low nutrient levels and the inorganic nature of lake bottom.	Varying in surface area from about 40 ha to several thousand ha. Very short retention time with large flow through.	Wide range of sizes. Typically very shallow with a flat bottom profile and short retention time.
Water quality	Start out oligotrophic (low nutrient levels) and eventually become eutrophic (nutrient rich). Impacted by culturally induced eutrophication.	See normal glacial lakes (except that water quality is significantly affected by sediment-related turbidity).	Water quality is a reflection of river water quality. High sediment-related turbidity, generated by rough fish, wind action, and runoff, is a major limiting factor. Generally high in nutrients with large amounts of sediment deposited when the river floods.

(continued)

TABLE 1. (continued)

Parameter	Natural Lakes		
	Glacial		Backwater
	Normal	Flowage	
Water quality	Exhibit classical symptoms associated with eutrophication (e.g., algal blooms, aquatic macrophytes, depletion of dissolved oxygen). Water transparency varies. Lakes tend to have a homogeneous water quality. Alkalinity, hardness, and conductivity are generally high. Ground water contributes to recharge.		
Watershed/ shoreline uses	Watersheds tend to be small, with the drainage area/lake capacity ratio also being small. Watershed is generally urban or suburban. Typically, having much development around the lakeshore.	Very large watersheds, with drainage area/ lake capacity ratios also extremely large. Otherwise, they are similar to normal glacial lakes.	Very large watershed. Usually having little shoreline development.
Lake usage	Very heavy recreational use, primarily boating, fishing, and swimming.	(See normal glacial)	Used primarily for flood protection, hunting, and fishing. Waterfowl habitat.

(continued)

TABLE 1. (continued)

Parameter	Natural Lakes		
	Glacial		Backwater
	Normal	Flowage	
Comments			Very difficult to manage and limit pollution inputs because of the riverine influence.

Parameter	Artificial Impoundments			
	Reservoirs			Other (Borrow Pits, Strip Mines, and Quarries)
	North	Central	South	
Location				Borrow pits are concentrated in or near urban centers and along highways. Generally, have long retention periods and are regulated by ground water level.
Physical/ morphological characteristics	Varying in surface area but with moderate to long retention. Maximum depth at the dam. Irregular shoreline.	Varying in surface area from very small to more than 4,000 ha. Short retention time with maximum depth at the dam. The lakebed is rich agricultural soil, high in nutrients and organic materials. The shoreline is irregular. Surficial recharge.	Varying in surface area with short to long retention time. Maximum depth at the dam. Very irregular shoreline. Lakebed consists primarily of claypan soils that are lower in nutrients and organic content than the central reservoirs. Surficial recharge.	

(continued)

Table 1. (continued)

Parameter	Artificial Impoundments Reservoirs North	 Central	 South	Other (Borrow Pits, Strip Mines, and Quarries)
Water quality	High alkalinity, conductivity, and hardness.	Medium to high alkalinity, conuctivity, and hardness. Generally eutrophic from the day reservoir started to fill. Extremely high nitrogen and phosphorus levels. Turbidity and siltation are major problems. May be light limited and, therefore, do not exhibit some of the secondary effects associated with classical eutrophication.	Low alkalinity, conductivity, and hardness. Generally clearer than central Illinois impoundments except when there is heavy runoff. Some have algae and macrophyte problems.	Clear unless there is heavy runoff. Wide range in water quality.
Watershed/ shoreline uses		Watersheds vary in size. Drainage area/lake capacity ratios vary. Watershed is primarily in row crops. Nonpoint pollution is a major problem. Some urban	Watersheds vary in size but are generally smaller than those of central Illinois. Watersheds are primarily forested or not under as intensive row crop cultivation as those of central Illinois.	Generally fed by ground water.

(continued)

Table 1. (continued)

Parameter	Artificial Impoundments			Other (Borrow Pits, Strip Mines, and Quarries)
	Reservoirs			
	North	Central	South	
Watershed/ shoreline		influence. There may be a moderate degree of development around the shoreline	Little urban influence except in some cases where developed along the shoreline.	
Lake usage	Recreation is the primary use. A few serve as public water supplies.	Many serve as public water supplies. Recreational usage is primarily fishing and boating.	Many serve as public water supplies. Recreational usage includes swimming, fishing, and boating.	

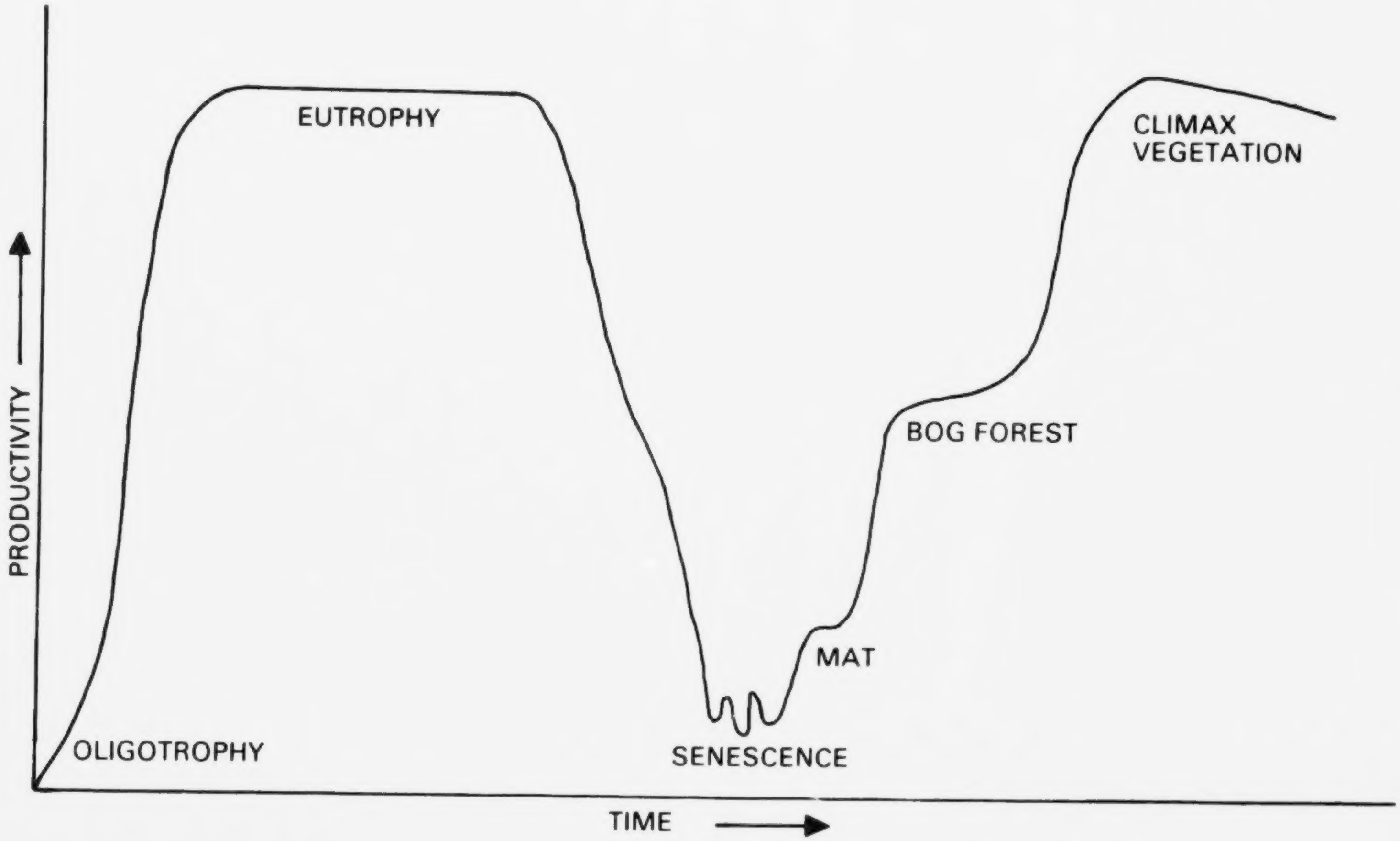

Figure 6. Hypothetical productivity growth-curve of a hydrosere (adapted from Lindeman 1942). Lindeman describes the curve as representing a hydrosere "developing from a moderately deep lake in a fertile cold temperate climatic condition." It must be kept in mind that this is a generalized curve and that not all lakes will follow it in total. For example, lakes that are light limited because of suspended inorganic materials may never experience the initial dramatic increase in productivity.

In Illinois lakes, sedimentation is considered to be more significant than lake production in terms of affecting their usable lifespan. Most Illinois lakes, whether recently impounded or old, have high productivity potential.

Eutrophication

The word eutrophication is often used to denote the process whereby a pristine water body (e.g., lake) is transformed into one characterized by dense algal scums, obnoxious odors, and thick beds of aquatic macrophytes. However, the word has been applied differently, according to the respective interests of its users. Weber (1907) used the German adjectival form of eutrophication, "nährstoffreichere" (eutrophe), to describe the high concentration of elements requisite for initiating the floral sequence in German peat bogs (Hutchinson 1973). The leaching of nutrients from the developing bog resulted in a condition of "mittelreiche" (mesotrophe) and eventually "nährstoffearme" (oligotrophe). Naumann (1919) applied the words oligotrophic (underfed), mesotrophic, and eutrophic (well-fed) to describe the nutrient levels (calcium, phosphorus, combined nitrogen) of water contained in springs, streams, lakes, and bogs (Hutchinson 1973). Naumann (1931) defined eutrophication as the increase of nutritive substances, especially phosphorus and nitrogen, in a lake. Hasler (1947) broadly interpreted eutrophication as the "enrichment of water, be it intentional or unintentional ...." Fruh et al. (1966) defined the word as the "... enhancement of nutrients in natural water ...." while Edmondson (1974) suggested that many limnologists seem to use the term to describe "... an increase in the rate of nutrient input ...." Hasler and Ingersoll (1968) suggested that eutrophication is the "... process of enrichment and aging undergone by bodies of fresh water ...." Vollenweider (1968) summarized the eutrophication of waters as meaning "... their enrichment in nutrients and the ensuing progressive deterioration of their quality, especially lakes, due to the luxuriant growth of plants with its repercussions on the overall metabolism of the water affected ...." A search of the literature on eutrophication indicates that the meaning of the term, originally limited to the concept of changing nutrient levels, has been gradually expanded to include the consequences of nutrient enrichment.

Eutrophication occurs both naturally and as a result of man's activities (cultural or anthropogenic eutrophication). Many of man's practices relating to the disposition of municipal sewage and industrial wastes and to land use impose relatively large nutrient loadings on many lakes and rivers. In many cases, the enrichment results in algal blooms and other symptoms of eutrophication. The consequences of man-induced eutrophication often make the water body less attractive to potential users. More importantly, at least when a long-range viewpoint is adopted, eutrophication accelerates lake succession and shortens the time period before a lake loses its identity.

A comment regarding eutrophication is in order. In the popular press and the mind of the layman, the term is equated with a "bad" or highly undesirable situation. Certainly when the enrichment levels reach extremes and undesirable manifestations occur (e.g., algal blooms, fish kills, obnoxious odors), the water body loses much of its value as a natural resource. However, enrichment of natural waters can result in increased primary productivity, leading to a larger biomass of consumers. Eutrophic water bodies often provide excellent warm-water fisheries.

The lakes of Illinois are undergoing eutrophication and the successional process as previously described. However, many of the lakes do not exhibit the secondary effects of eutrophication (e.g., algal blooms) because the silt-related turbidity of these waters greatly reduces light penetration, resulting in light-limited conditions. Water quality in Illinois streams and lakes is appreciably affected by dissolved and suspended matter carried by runoff from the land surface. IEPA (1976) provides an overview of the situation in Illinois; the following paragraph draws heavily from their reports.

Agricultural runoff and soil erosion are two nonpoint sources that affect the water quality of Illinois lakes and streams. Other major nonpoint sources (of a more localized nature) that affect water quality include active and abandoned coal-mining areas, intensive livestock and specialized agricultural operations, and storm drainage from urbanized areas and construction sites. Agricultural runoff and runoff from ordinary precipitation events contain many contaminants (e.g., organic materials that are oxygen demanding, minerals derived from the soil or applied by man, fecal coliform bacteria, pesticides, herbicides, fertilizers, and other chemicals) from ground surface and ground cover that have accumulated through natural processes and nonintensive land husbandry. When rainfall of sufficient intensity occurs, soil erosion results. The severity and frequency of soil erosion is a function of many factors including intensity of immediate rainfall, prior climatic conditions, soil cover, soil texture, topography, and antecedent human activities. The eroded soil contributes both dissolved and suspended matter to the flowing waters. The suspended matter may impair the recreational use of the body of water as well as such vital biological functions as photosynthesis, respiration, reproduction, feeding, and growth. The suspended materials contributed by agricultural runoff and erosion may also be deposited in streambeds and lake beds. The deposited soil can bury aquatic life, create an oxygen demand, and release nutrients and chemicals to the flowing stream or overlying lake water. The influx of nutrients to a lake, assuming they are not deposited on the bottom and overlain by other materials, tend to make the water body more eutrophic. The accumulation of materials on the lake or reservoir bottom decreases the water depth and moves the water body closer to the time when its identity as a lake or reservoir is lost.

SECTION 5

METHODOLOGICAL OVERVIEW

Most attempts to classify or ordinate lakes employ contact-sensing techniques coupled with the observations of the field crew to document the characteristics of the water bodies. The major constraints of most classification systems are the neccessity for elaborate field data, difficulties in obtaining data for all lakes within a comparable time period or comparable physical circumstances, and lack of sufficient or appropriate sample locations to characterize the entire lake.

A good historical data base for most lakes in Illinois is either not available or not suited to the development of an overall lake classification system. Several attempts to characterize these lakes according to sample data and field observations have had limited usefulness since the data were not intensively collected within a short time period and since they relied, in part, upon subjective observations of field personnel. It appears that satellite-borne sensors such as the multispectral scanner carried by LANDSAT are capable of collecting data of value for lake classification and monitoring activities. The LANDSAT space observatories are attractive because they provide repetitive coverage, a synoptic view, and a permanent record. The LANDSAT capabilities offer a unique opportunity to obtain a data base that could group the lakes into categories according to their spectral responses and also provide the opportunity to study relationships between certain trophic indicators and the spectral data with an eye toward the development of predictive models. LANDSAT provides what may be an economically viable technique for collecting data for the entire surface area of each lake within a reasonable time period. In about 25 seconds the LANDSAT multispectral scanner (MSS) collects data in four bands of the spectrum for an area of the earth covering about 34,225 square kilometers. In regions of the earth where lakes are very abundant, a typical LANDSAT scene may contain several hundred to more than a thousand inland water bodies. With two satellites in operation and assuming cloud-free conditions, repetitive coverage is provided on a 9-day basis. Clearly, the satellite offers certain advantages over conventional contact-sensing techniques. Before discussing in more detail the characteristics, capabilities, and limitations of LANDSAT in the area of lake classification, it is necessary that we examine the optical properties of water.

OPTICAL PROPERTIES OF PURE WATER AND NATURAL WATERS

It is readily apparent, even to the casual observer, particularly if he or she is looking downward from an aircraft, that lakes differ in color and brightness. Many investigations have been undertaken to develop an understanding of the processes that result in the observed phenomena. Although a detailed description of the interaction between electromagnetic energy and the components of the hydrosphere and atmosphere is outside the scope of this report, a brief discussion is essential to gain some understanding of the principles that both permit and yet constrain the use of remote-sensing techniques in lake classificatory work.

The interaction between electromagnetic energy and chemically pure water has been studied by numerous investigators (e.g., Ewan 1894, Sawyer 1931, Collins 1925, James and Birge 1938, Hulburt 1945, Raman 1922, Dawson and Hulburt 1937). The transmission of electromagnetic energy through a material medium is always accompanied by the loss of some radiant energy by absorption. Some of the energy is transformed into other forms (e.g., chemical) or to some longer wavelength of radiation (e.g., thermal infrared) (James and Birge 1938). Pure water is very transparent to violet, blue, and green light. In the infrared region, the extinction coefficient is high with a complementary low degree of transmission (Table 2). The absorption spectral characteristics of pure water can be modified greatly through the addition of dissolved and particulate materials.

The absorption spectra of natural waters (e.g., lake and ocean) have been studied in detail by Jerlov (1968), Duntley (1963), Atkins and Poole (1952), Birge and Juday (1929, 1930, 1931, 1932), and Juday and Birge (1933), to mention a few. Hutchinson (1957) has summarized the more important attempts to elucidate the interactions of light with natural waters, particularly with regard to lakes.

An electromagnetic wave impinging on the surface of a lake decomposes into two waves, one of which is refracted and proceeds into the aquatic medium and the other of which is reflected back to the atmosphere (Jerlov 1968). The wave entering the water is refracted as it passes through the air-water interface according to Snell's Law, which may be expressed as

$$n = \sin(i)/\sin(r)$$

where

(i) = angle of incidence

(r) = angle of refraction

n = refractive index, which for water is approximately 1.33.

Most of the electromagnetic energy entering a lake is attenuated through the process of absorption. Although only a small percentage (less than 3 percent) (Davis 1941) of the incident energy is backscattered from the lake water volume, this light (volume reflectance) is the focus of interest in the

TABLE 2. OPTICAL PROPERTIES OF PURE WATER (ROOM TEMPERATURE)*

Wavelength (nanometers)	Extinction Coefficient	Percentile Absorption	Refractive Index
820 (near infrared)	2.42	91.1	
800	2.24	89.4	
780	2.31	90.1	
760	2.45	91.4	1.329
740	2.16	88.5	
720	1.04	64.5	
700	0.598	45.0	
680 (red)	0.455	36.6	
660	0.370	31.0	1.331
640	0.310	26.6	
620 (orange)	0.273	23.5	
600	0.210	19.0	
580 (yellow)	0.078	7.0	1.333
560	0.040	3.9	
540	0.030	3.0	
520 (green)	0.016	1.6	
500	0.0075	0.77	
480	0.0050	0.52	1.338
460 (blue)	0.0054	0.52	
440	0.0078	0.70	
420	0.0088	0.92	
400 (violet)	0.0134	1.63	1.343
380 (ultraviolet)	0.0255	2.10	

*Adapted from Hutchinson (1957)

remote-sensing aspect of water quality investigations. Its spectral characteristics have been shaped by the materials found in the lake's waters (dissolved and suspended materials, plankton, aquatic macrophytes, and air bubbles).

The attenuation of electromagnetic radiation in lake waters is a consequence of the relatively unselective effect of suspended particulate materials and the highly selective effect of dissolved coloring matter, usually of organic origin, on the electromagnetic spectrum. The dissolved matter absorbs strongly in the violet and blue wavelengths, moderately in the middle wavelengths (e.g., green), and only weakly at longer wavelengths (Hutchinson 1957). When the dissolved materials are present in small quantities, the water will be most transmissive in the green wavelengths. Lake waters with large amounts of dissolved substances are more transmissive in the orange and red wavelengths than in the shorter wavelengths. However, the transmission of red and orange light is still greater in pure water than in water containing particulate or dissolved materials. As water transparency diminishes, the detectable electromagnetic energy will be of progressively longer wavelength at increasingly shallower depths (Hutchinson 1957).

The color of a lake is the color of the electromagnetic energy backscattered from the lake body and reflected from the lake surface to the sensor. Lake color need not be, and is usually not, the same as the color of the lake's water. Lake color ranges from the blue of pure water through greenish blue, bluish green, pure green, yellowish green, greenish yellow, yellow, yellow brown, and clear brown (Hutchinson 1957). Welch (1952) defines water color as "... those hues which are inherent within the water itself, resulting from colloidal substances or substances in solution" (i.e., true color). Lakes that are blue in color lack appreciable quantities of humic materials and colored materials in suspension (e.g., phytoplankton). The bluer the lake color, the smaller the amount of free-floating organisms contained in the water (Ruttner 1963). Waters with a high plankton content possess a characteristic yellow-green to yellow color. The characteristic color may not be apparent because of masking by other materials (e.g., suspended sediments). Ruttner (1963) suggested that:

> "A lake with very transparent and dark blue, blue-green or green water is always oligotrophic. On the other hand, eutrophic lakes always have a relatively low transparency and are yellow-green to yellow-brown in color; but the determination of these optical properties alone will not establish the productivity type, for the turbidity can be of inorganic origin, and the color can come from humic substances."

Seston color (color that is attributable to the reflection spectra of suspensoids of microscopic or submicroscopic size) is often observed in highly productive lakes. Lakes containing large quantities of suspended inorganic matter (e.g., silt) may acquire a characteristic seston color, but in most cases the color is related to large concentrations of phytoplanktonic organisms (Hutchinson 1957).

Scherz et al. (1969) have investigated the total reflectance (surface reflectance plus volume reflectance) curves of pure water and natural waters under laboratory conditions using a spectrophotometer. They reported that the addition of dissolved oxygen, nitrogen gases, and salts (e.g., NaCl, Na_2SO_4, $Na_3PO_4 \cdot H_2O$) had no apparent effect on the reflection curve However, water from lakes in the Madison, Wisconsin, area had reflectance curves that differed both from the distilled water curve and from each other. They attribute these differences to the presence of different algal organisms, since filtration of the lake waters produced similar reflectance curves for all lakes even though the curves differed from those of pure water (Figure 7).

The color of natural waters is the end result of optical processes that are both numerous and complex. It is relatively easy to detect differences

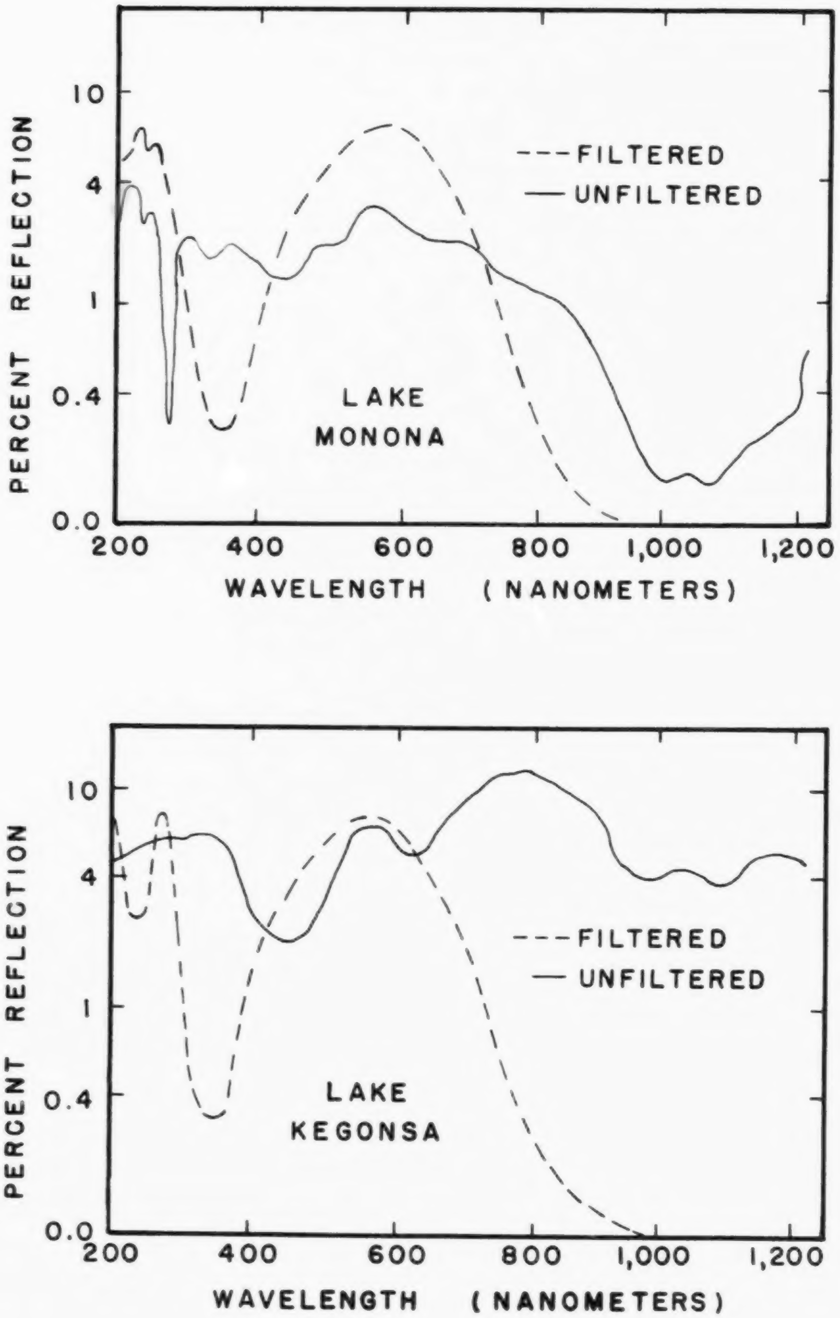

Figure 7. Reflection characteristics of filtered and unfiltered water samples from two Wisconsin lakes in the area of Madison (adapted from Scherz et al. 1969).

in color within a lake and also among a population of lakes. It is, however, more difficult to attach physical, chemical, or biological significance to the color, particularly when quantitative estimates are desired. The difficulty is compounded in waters having more than one class of particulates present, which is normally the case in natural water (McCluney 1976), and by seasonal differences in color within a lake. The degree of success in sensing and interpreting the significance of color is partially a function of the sensor type employed for the collection of spectral data.

LANDSAT MULTISPECTRAL SCANNER

Scanner Characteristics

The LANDSAT MSS is a line-scanning radiometer that collects data by creating images of the earth's surface in four spectral bands: Green (GRN) 500 to 600 nanometers (nm); Red (RED) 600 to 700 nm; near infrared-one (IR1) 700 to 800 nm; near infrared-two (IR2) 800 to 1,100 nm.

The MSS scans crosstrack swaths 185 km in width, simultaneously imaging six scan lines for each of the four bands (Figure 8). The resultant analogue signals are sampled, digitized, arranged into a serial digit data stream, and transmitted to ground stations either in real time or by delayed transmission. LANDSAT data enter the public domain through the U.S. Geological Survey's EROS (Earth Resources Observation System) Data Center near Sioux Falls, South Dakota. The data are available in the form of photographic products (e.g., black-and-white prints) and computer-compatible tapes (CCT's). The CCT's contain the data in digital form.

The MSS, as found on LANDSAT-1, -2, and -3, is a low resolution device, both spatially and spectrally speaking. Three of the bands (GRN, RED, and IR1) are 100 nm in width while the IR2 band covers 300 nm. Figure 9 illustrates a generalized spectral reflectance curve for a single picture element (the MSS spatial resolution unit, also called a pixel) of a hypothetical lake. The width of the MSS bands disallows the recording of the fine details in the curve. The MSS output more closely resembles Figure 10. Responses are given as values for the various wavelengths bands (e.g., 500 to 600 nm, GRN) instead of specific values for the entire spectral range. This procedure crudely defines an entire range of wavelength responses as four single readings.

The nominal MSS pixel measures 57 by 79 meters, and covers an area of 0.3933 hectares (ha). Through the use of resampling techniques it is possible to adjust the pixel size (e.g., an 80-meter by 80-meter pixel corresponding to 0.64 ha was employed in this study). It must be kept in mind that the MSS gathers energy over the area of its nominal pixel. Many measurements made using contact techniques are of the point type, a direct contrast to those acquired by the LANDSAT MSS. It is commonly recognized that some LANDSAT MSS pixels contain a mixture of water and land features. This normally occurs along the water-land interface or in situations where the water body.is much smaller than the pixel or, conversely, where an island is much smaller than the pixel. The pixel size also tends to give small water bodies or those with very irregular shorelines a "blocky" appearance.

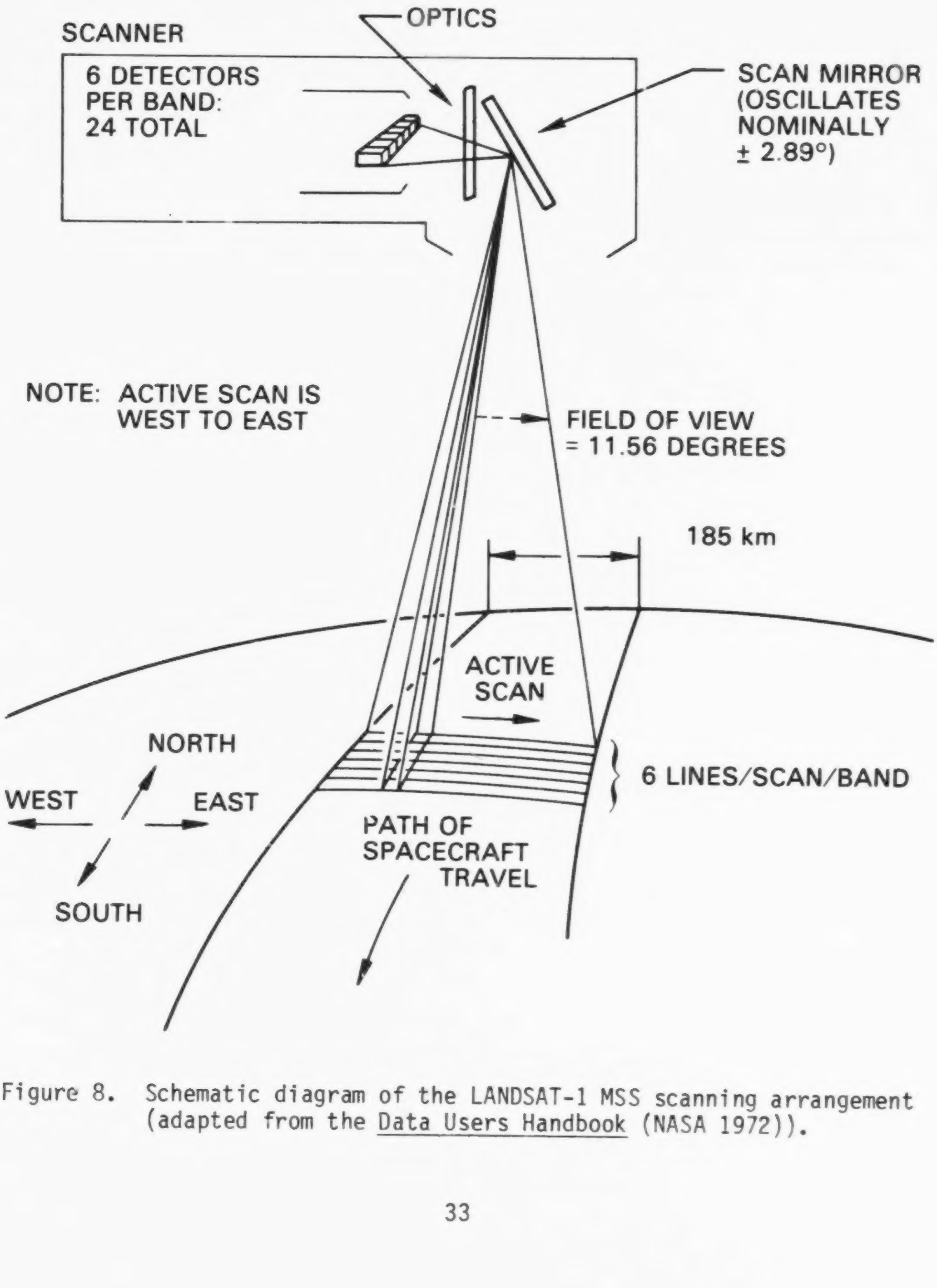
SCANNER
OPTICS
6 DETECTORS PER BAND: 24 TOTAL
SCAN MIRROR (OSCILLATES NOMINALLY ± 2.89°)
NOTE: ACTIVE SCAN IS WEST TO EAST
FIELD OF VIEW = 11.56 DEGREES
185 km
ACTIVE SCAN
NORTH
WEST
EAST
SOUTH
6 LINES/SCAN/BAND
PATH OF SPACECRAFT TRAVEL

Figure 8. Schematic diagram of the LANDSAT-1 MSS scanning arrangement (adapted from the Data Users Handbook (NASA 1972)).

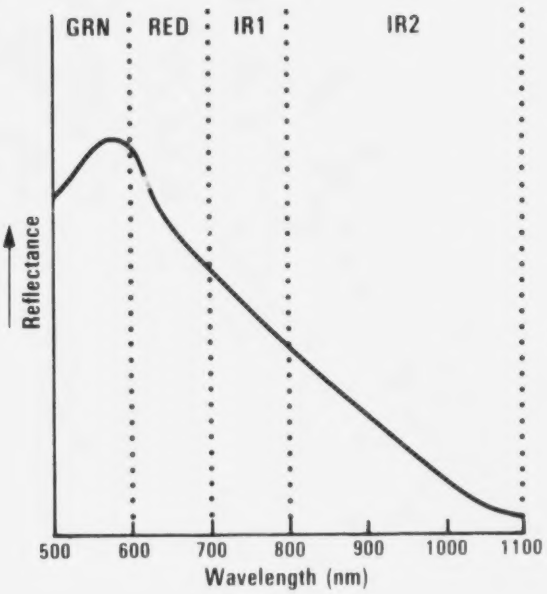

Figure 9. Generalized spectral reflectance curve for a single picture element (pixel) of a hypothetical lake.

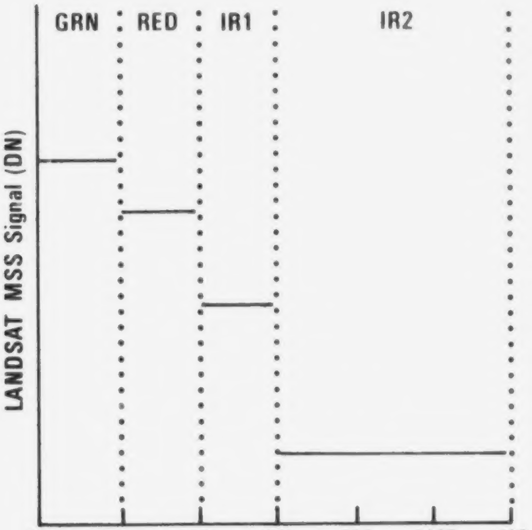

Figure 10. Generalized output of the LANDSAT MSS in response to the spectral distribution illustrated in Figure 9.

A visual examination of imagery generated from the LANDSAT MSS will usually detect a pattern of stripes running nearly orthogonal to the satellite's path. This is a consequence of an imbalance among the MSS's 24 detectors. The problem is particularly noticeable when working in the digital domain (i.e., with the CCT's).

It should be kept in mind that, although the LANDSAT MSS was designed with the earth's resources in mind, it was not developed specifically for water. Most of the incident solar energy entering a water body is attenuated through absorption. The volume reflectance of a water body is generally less than three percent of the incident light. Thus, the energy reaching the MSS from water bodies is relatively small in magnitude compared to that received from land features. While it is possible to increase the MSS's gain in the GRN and RED bands, this is not normally done.

Peripheral Effects

The character of the electromagnetic energy impinging on the remote sensor, the LANDSAT-1 MSS in this case, has been shaped through interactions with numerous environmental phenomena (Figure 11). Some of the interactions are highly desirable because they mold the character of the light, which may then be interpreted in terms of some parameter of interest (e.g., Secchi depth). Other interactions of light energy with the environment (e.g., atmospheric scatter) may be detrimental to a particular study. What may be a vitally important interaction in one study may be devastating in another.

The earth's atmosphere has a pronounced effect on the solar spectrum and on lake water color as sensed from aircraft and satellite altitudes. Atmospheric conditions (e.g., degree of cloudiness; presence of fog, smoke, and dust; amount of water vapor) affect the degree of insolation attenuation. Weather conditions strongly affect the distribution of energy between sunlight and skylight (Piech and Walker 1971), contributing a degree of uncertainty in water quality assessment through remotely sensed color measurements. Hulstrom (1973) has pointed out the adverse impact that cloud bright spots can have on remote-sensing techniques that utilize reflected energy.

The degree of scattering and absorption imposed on the return signal from water bodies is related to atmospheric transmittance and can result in changes in lake color when sensed at aircraft-high flight and satellite altitudes. The attenuated return signal is also contaminated by electromagnetic radiation from the air column (path radiance). Rogers and Peacock (1973) have reported that solar and atmospheric parameters have a serious adverse impact on the radiometric fidelity of LANDSAT-1 data. Path radiance was found to account for 50 percent or more of the signal received by the MSS when viewing water and some land masses. The magnitude of the adverse atmospheric effects can be reduced, though not completely eliminated, by using imagery or digital data collected on clear, cloudless days. This is the approach used in this investigation.

The LANDSAT-1 spacecraft passes over the same point on the earth at essentially the same local time every 18 days. However, even though the time

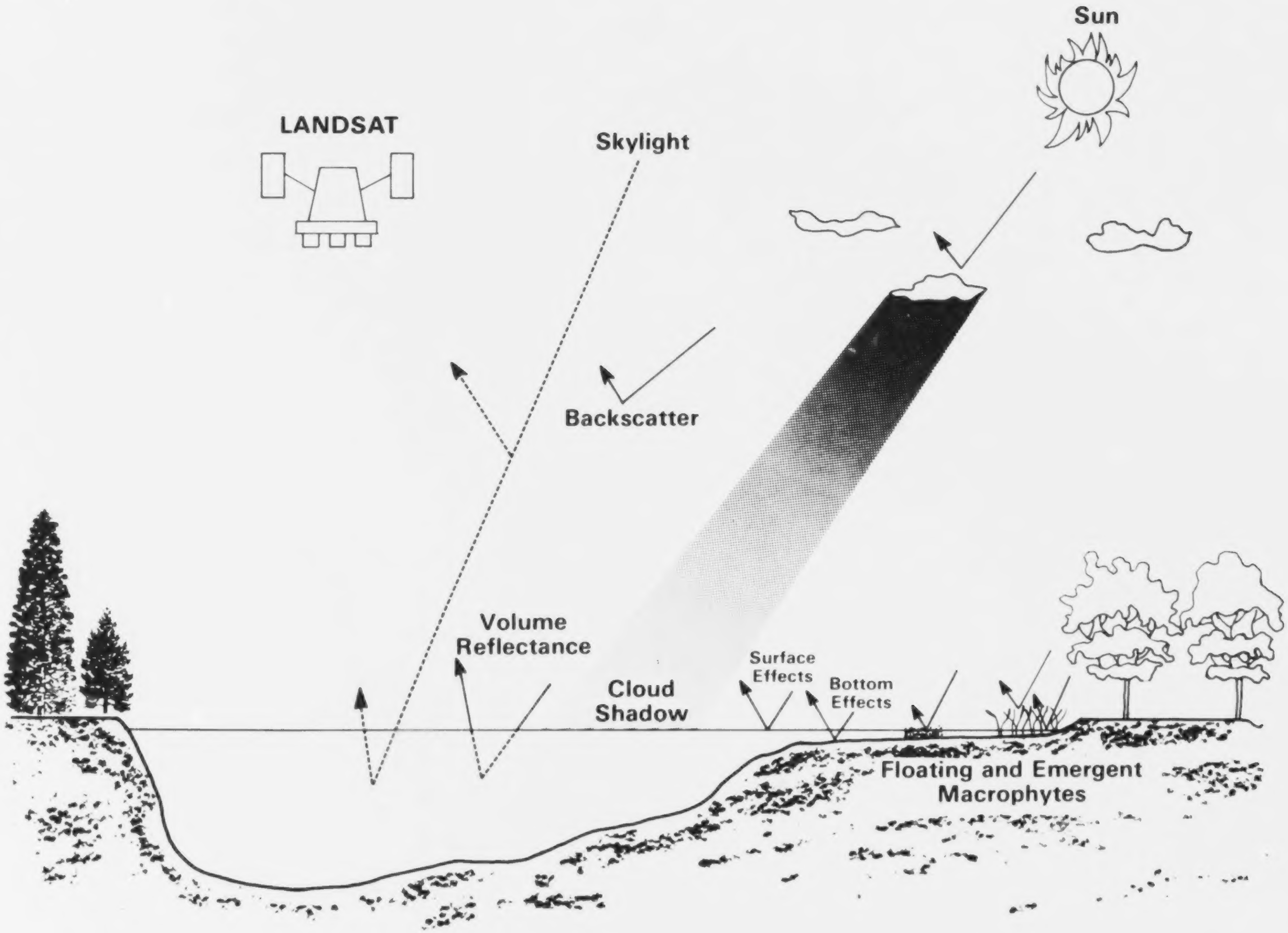
Sun
LANDSAT
Skylight
Backscatter
Volume
Reflectance
Cloud
Shadow
Surface
Effects
Bottom
Effects
Floating and Emergent
Macrophytes

Figure 11. Some components and interactions of light with a hypothetical lake and the atmosphere.

of flyover will remain essentially the same throughout the year, solar-elevation angle changes cause variations in the lighting conditions under which the MSS data are obtained. The changes are primarily the result of the north or south seasonal motion of the sun (NASA 1972). Changes in solar-elevation angle produce changes in the average scene irradiance as seen by the sensor from space. The change in irradiance is influenced both by the change in the intrinsic reflectance of the ground scene and by the change in atmospheric backscatter (path radiance). The actual effect of a changing solar-elevation angle on a given scene is very dependent on the scene itself (NASA 1972). For example, the intrinsic reflectance of sand is significantly more sensitive to a changing solar-elevation angle than are most types of vegetation (NASA 1972). The effects of a changing solar-elevation angle are of particular importance when comparing scenes taken under significantly different angles. The use of color ratios in lieu of raw data values may be of value in reducing the magnitude of the solar angle-induced effects by normalizing the brightness components. The approach is given some consideration in this study.

A portion of the radiation impinging on the lake surface will be reflected. The percentage of surface-reflected energy is a strong function of the angle of incidence. The light reflected from the water-atmosphere interface is composed of diffuse light from the sky (skylight) and specularly reflected sunlight. Specular reflection areas contained in a scene are of little value in most water studies, the possible exception being the determination of surface roughness. The specularly reflected radiation exceeds, by several orders of magnitude, the reflected energy emanating from beneath the water surface (Curran 1972). Surface-reflected skylight, containing no water-quality color information, can comprise from 10 percent of the return signal on a clear day to 50 percent on a cloudy day (Piech and Walker 1971). The surface-reflected skylight not only increases the apparent reflectance from the water body (volume reflectance) but also affects the shape of the reflectance curve. Surface roughness is known to have an effect on the percentages of light reflected and refracted at the interface (Jerlov 1968). However, the effect of surface roughness is negligible in estimating total radiation entering a water body when the solar-elevation angle is greater than 15 degrees (Hutchinson 1957).

The lake bottom characteristics (color and composition) will also affect the intensity and the spectrum of the volume reflectance in settings where water transparency permits the reflection of a significant amount of radiation from the bottom materials. In studies involving the estimation of water depth or the mapping of bottom features, it is essential that the lake bottom be "seen" directly or indirectly by the sensor. Bottom effects are capitalized upon and put to a beneficial use. However, in this investigation, bottom effects are considered to be an undesirable peripheral effect. A sensor with the capabilities of the LANDSAT MSS is not able to "see" much deeper into a lake than the Secchi depth. The Secchi transparency of Illinois lakes is, in most cases, relatively small (e.g., less than one meter) when compared to the mean depth of each lake. The assumption is made, as a first approximation, that the bottom effect is relatively insignificant when considering each of the selected lakes as an entity.

It is evident that many factors influence the intensity and spectral characteristics of the electromagnetic radiation that is collected by the sensor. Absolute quantification of remotely sensed phenomena requires that all of the adverse effects be accounted for in the return signal. Failure to account for all of the variation introduced by the detrimental effects might be criticized as being simplistic or naive. However, given the present "state of the art" along with manpower, time, and monetary constraints, and the ex post facto nature of the project, a complete accounting is not possible.

SATELLITE SENSING OF ILLINOIS LAKES

A visual examination of LANDSAT MSS imagery indicates that gray-tone differences can be detected in the study population of Illinois lakes. Figures 12 through 15 represent, respectively, the IR2, IR1, RED, and GRN gray-tone images of LANDSAT scene 1448-16023. The IR2 image (Figure 12) clearly demonstrates a great contrast between water bodies and terrestrial features. Water is an excellent absorber of radiation wavelengths comprising the IR2 band, so water bodies appear black. Figure 13, the scene's IR1 counterpart, exhibits a similar contrast between water and land. A careful examination of the water bodies suggests surface or near-surface phenomena in some lakes. Gray-tone differences both within specific water bodies and among members of the lake population are most pronounced in the RED image (Figure 14). In this band, lakes with extremely turbid water often meld with the terrain features, a consequence of similar gray-tone values. A vivid example is presented in Boland (1976). Though less obvious to the eye, gray-tone differences are also noted among water bodies in the GRN-band image (Figure 15).

When viewing LANDSAT scenes such as the black-and-white standard photographs produced by the EROS Data Center, it should be kept in mind that no special effort has been made to enhance water bodies and related phenomena. Indeed, a loss of spectral information occurs when the MSS digital data are transformed into photographic products. Specifically, the products have a relatively small density range compared to the sensitivity range of the MSS. This results in a scale compression when the MSS data are transformed into a film image on an electron beam recorder. In addition, the range of energy returns from water bodies is small and concentrated at the lower end of the MSS intensity scale. Scale compression coupled with the small range of digital number (DN) values adds to the difficulty of determining trophic state index and indicator values through visual and densitometric evaluation of "standard" EROS black-and-white photographs.

As can be seen from Figures 12, 13, 14, and 15, it is possible to detect spectral differences for Illinois lakes using LANDSAT imagery coupled with photointerpretive techniques. The real problem is one of relating the spectral variations to chemical, biological, and physical phenomena measurable through contact-sensing techniques or acquired through ground-level observation.

As indicated earlier, the quantity and spectral composition of radiation directed upward across the water-atmosphere interface is, in part, a function

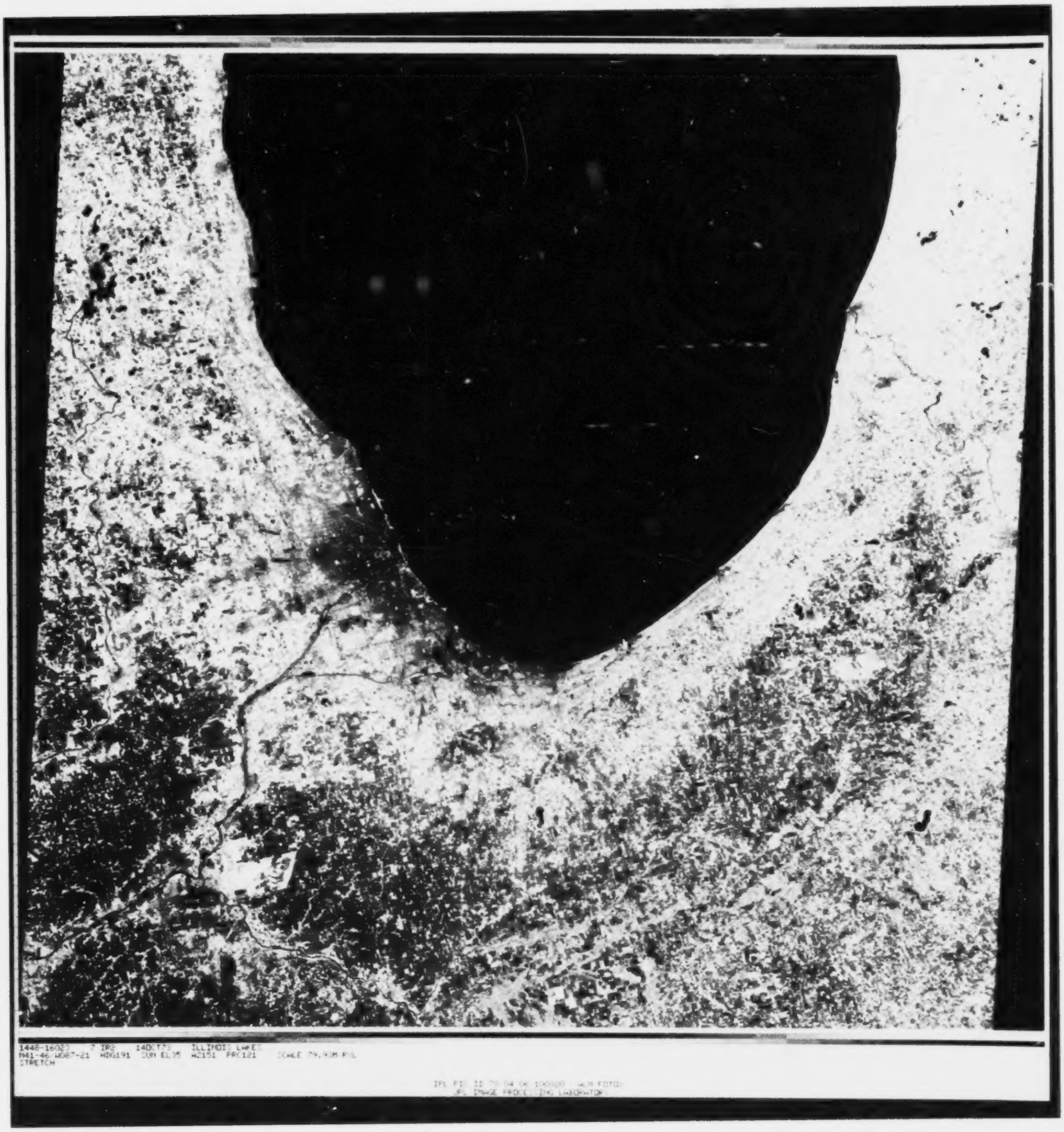
1448-16023 7 IR2 14OCT73 ILLINOIS LAKES
N41-46 W087-21 HDG191 SUN EL35 AZ151 PRC121 SCALE 79.93M P/L
STRETCH
IPL PIC ID 75/04/06 100320 ... FOTO
JPL IMAGE PROCESSING LABORATORY

Figure 12. IR2 image of LANDSAT scene 1448-16023 (October 14, 1973). The IR2 band is excellent for separating water bodies from land.

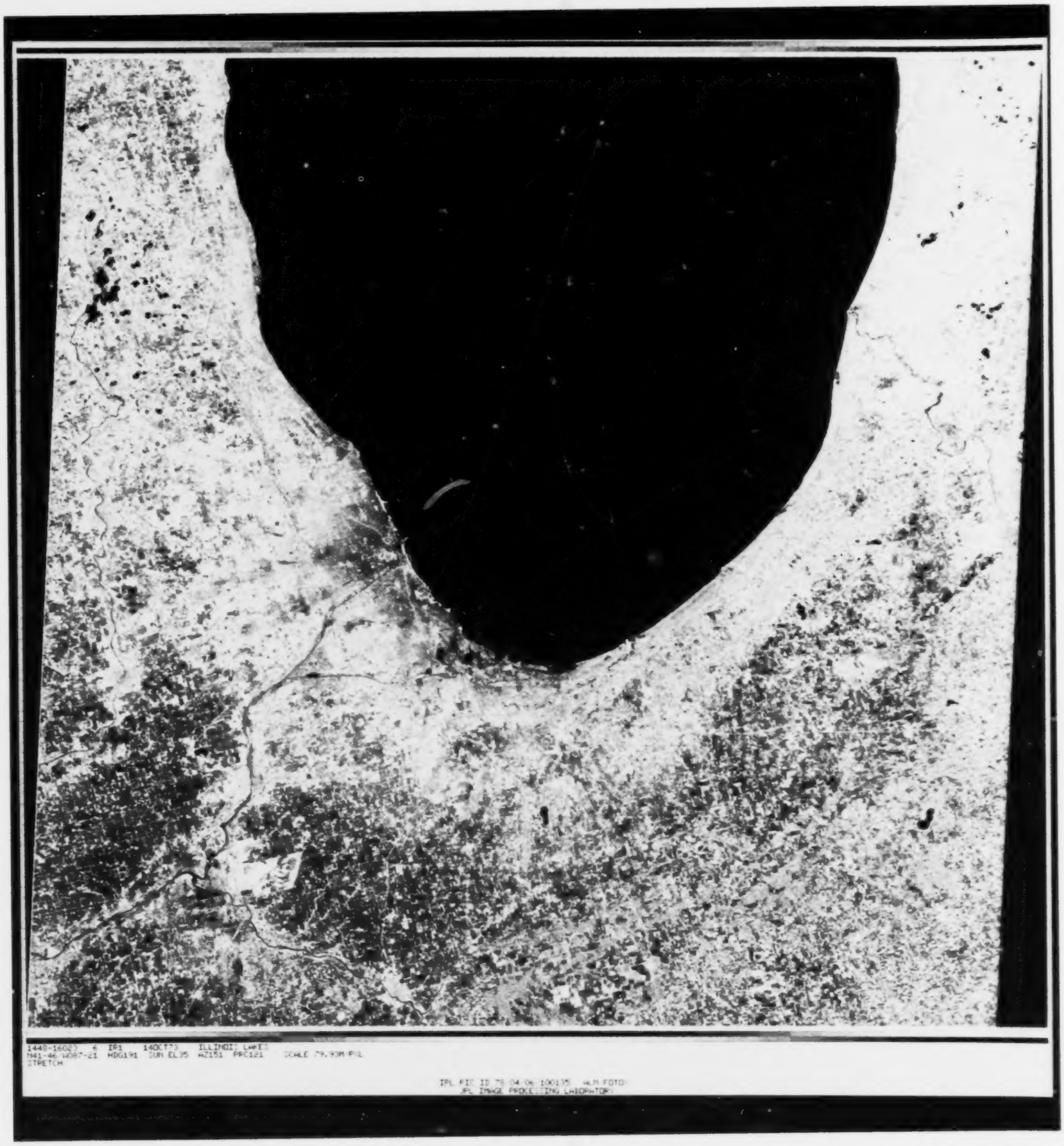
1448-16023 6 IR1 14OCT73 ILLINOIS LAKES
N41-46 W087-21 HDG191 SUN EL35 AZ151 PRC121 SCALE 79.93M PXL
STRETCH
IPL PIC ID 78/04/06 100135 ALM FOTO
JPL IMAGE PROCESSING LABORATORY

Figure 13. IR1 image of LANDSAT scene 1448-16023 (October 14, 1973). The band is excellent for discriminating water from terrain. Surface or near-surface phenomena are evident in some of the water bodies.

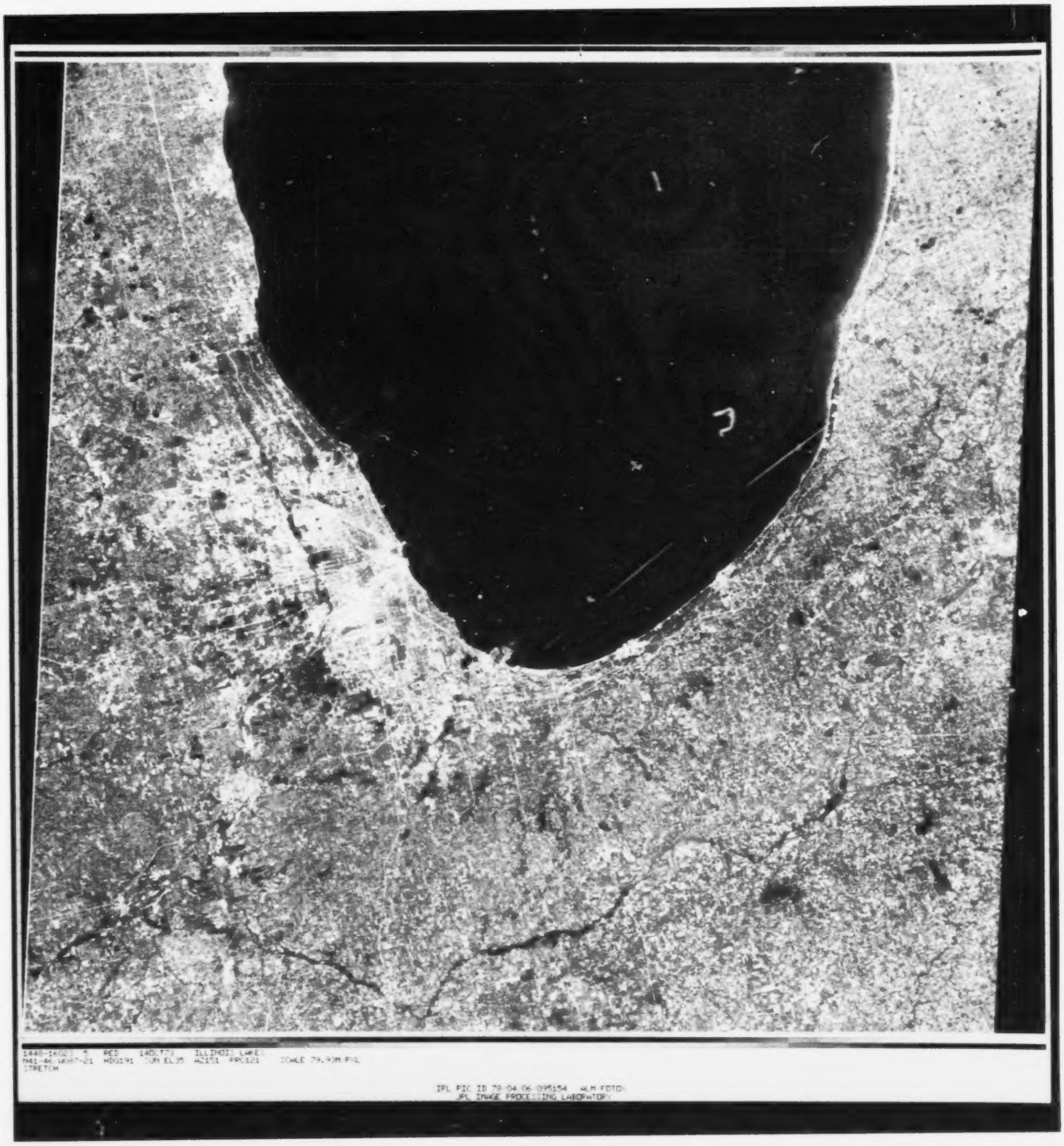
1448-16023 5 RED 14OCT73 ILLINOIS LAKES
N41-46 W087-21 HDG191 SUN EL35 AZ151 PPC121 SCALE 79.93M PXL
STRETCH
JPL PIC ID 78/04/06/095154 ALM FOTO
JPL IMAGE PROCESSING LABORATORY

Figure 14. RED image of LANDSAT scene 1448-16023 (October 14, 1973). Variations in water body gray tones suggest differences in water quality.

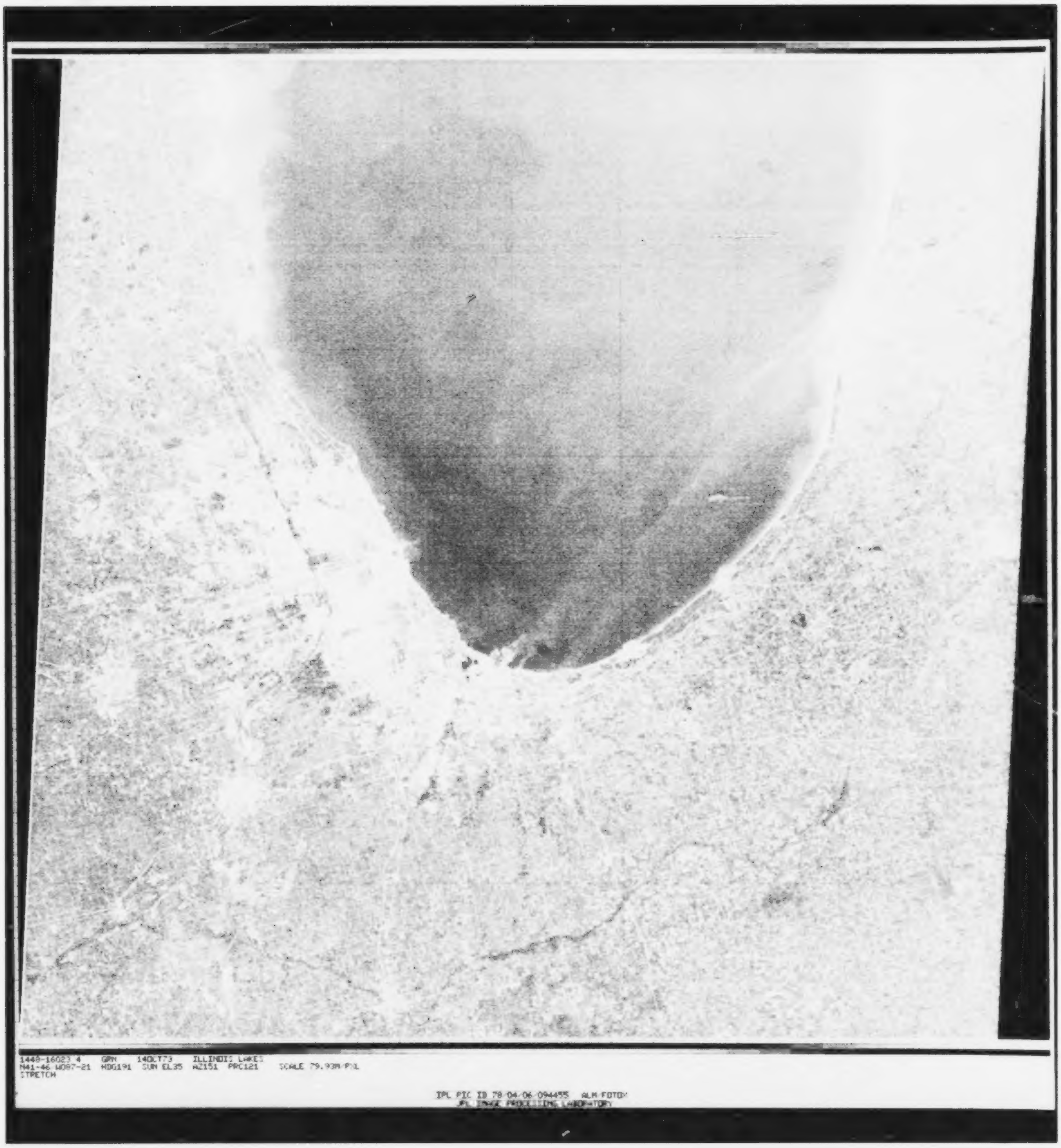
1448-16023 4 GRN 14OCT73 ILLINOIS LAKES
N41-46 W087-21 HDG191 SUN EL35 AZ151 PRC121 SCALE 79.93M/PXL
STRETCH
IPL PIC ID 78/04/06/094455 ALM FOTOX
JPL IMAGE PROCESSING LABORATORY

Figure 15. GRN image of LANDSAT scene 1448-16023 (October 14, 1973). While lacking the contrast of the RED, IR1, and IR2 images of the scene, gray scale differences are still evident among the water bodies. Compare with Figures 12, 13, and 14.

of the dissolved substances and particulate materials in the water. While water itself is capable of scattering and absorbing light, the major portion of the scattering is caused by materials in the water. Scattering as a result of dissolved color is highly selective, while suspended solids tend to affect volume reflectance in a rather nonselective fashion. It then follows that increases in suspended particulate materials in lake water will tend to increase the reflectance in the LANDSAT bands.

It should be noted that some natural waters will, at least for a portion of the spectrum, exhibit a lower volume reflectance than pure water. Humic waters have this characteristic as demonstrated by Rogers (1977) and shown in Figure 16. Humic or "brown water" lakes are relatively common in the northern portions of Minnesota, Wisconsin, and Michigan. They are much less common in Illinois, and none of the lakes included in this project are of the humic type.

Rogers (1977) and Scherz et al. (1975) have demonstrated a simple and practical technique to determine the spectral signatures of lakes. The term "satellite residual fingerprint" is used to identify the isolated spectral signature. Their approach is as follows.

If a very deep, clear lake is found in a LANDSAT scene, and assuming that bottom signals are not present or at least are insignificant, it follows that the electromagnetic signal received from the lake by the MSS is attributable to lake surface signals, plus a very small amount of backscatter from the water molecules, and atmospheric effects. If another lake containing dissolved and or suspended solids that interact with light is present in the scene, then subtracting the spectral band values for the clear lake from the corresponding band values of the second lake will result in a residual spectral curve that is related to the impurities present. Computation of the difference for one or several MSS bands can result in the aforementioned satellite residual fingerprint. A graphic example of the technique is seen in Figure 17. The upper portion of the figure illustrates the raw spectral curves (i.e., spectral signatures) for three Wisconsin water bodies: Yellow Lake (algal-laden), Moose Lake (humic), and Grindstone Lake (clear). The lower set of curves (i.e., satellite residual fingerprints) were obtained by subtracting the clear lake MSS DN value for each band from its counterpart in each of the other lakes.

Though lacking the elegance often associated with attempts to remove atmospheric effects through mathematical modeling, the satellite residual fingerprint technique has much appeal. It is, however, dependent on the presence of deep, clear lakes. With the exception of Lake Michigan, Illinois lacks such lakes.

Piech and Walker (1971) have demonstrated a method called the scene color standard (SCS) technique* for the removal of peripheral effects in water quality surveys. The technique is attractive because no ground truth is required for removing the peripheral effects. The SCS approach employs a

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* Patent pending.

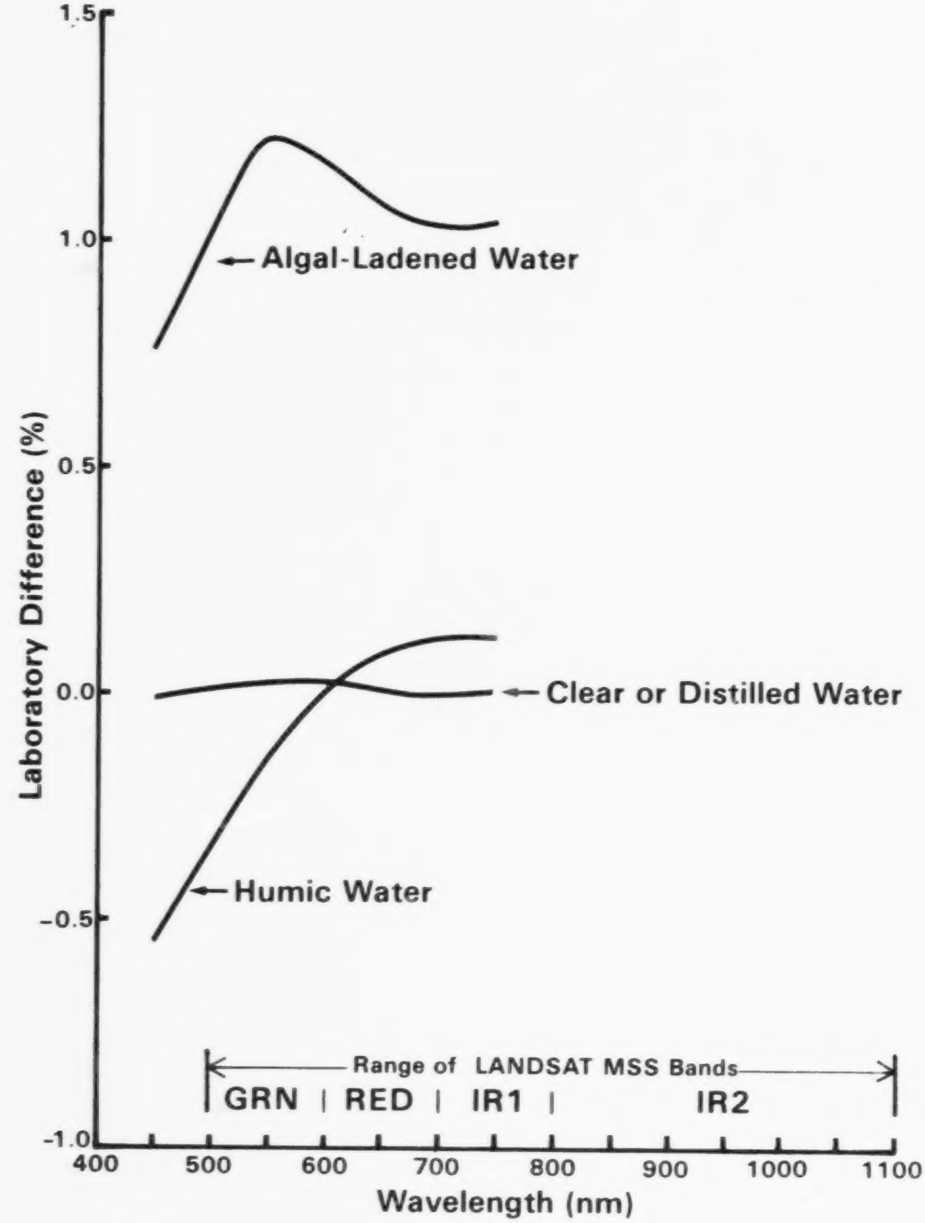


Figure 16. Characteristic "fingerprints" of clear or distilled water, humic water, and algal-laden water. The ordinate is scaled in percentage of laboratory difference ($D_i = (p_{vi} - p_{v1})/p_{p1}$ where p_{vi} and p_{v1} are the volume reflectances for the water in question and distilled water, respectively, and p_{pL} is the "fingerprint" obtained under laboratory conditions (adapted from Rogers (1977).

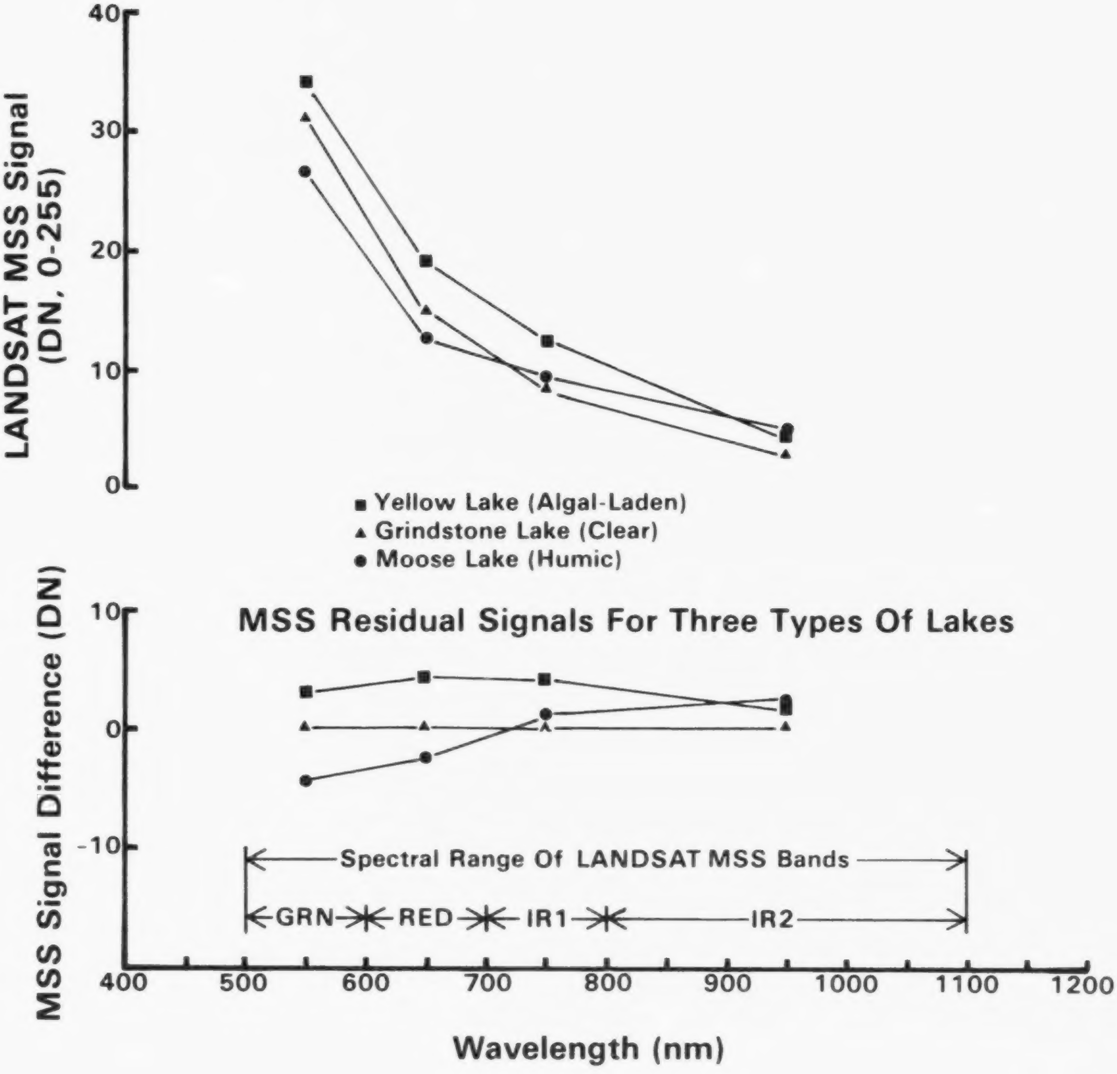


Figure 17. LANDSAT MSS spectral signatures and residual curves for three types of lakes (modified from Rogers (1977)).

combination of known reflectances from natural objects and certain characteristic shadow areas within the scene. Unfortunately, shadows of a size compatible with the spatial resolution of the LANDSAT MSS are either lacking in the Illinois scenes or confined to a geographically restricted area. In addition, the reflectances of sunlit natural objects in juxtaposition with the shadows (in this case cloud shadows) are not known. Therefore, the SCS technique cannot be employed to remove the peripheral effects from Illinois MSS lake data available for this project.

It has been well documented that the MSS is incapable of directly detecting substances such as nutrients (e.g., phosphorus) in water. This does not mean, however, that it is impossible to get some estimate of such substances. Phosphorus, for example, is known to be a key element in primary productivity, stimulating the production of biomass. Differences in nutrient levels are often directly related to the magnitude of the manifestations of eutrophication (e.g., turbidity, chlorophyll a, algal blooms). Such phenomena are sensible to the MSS. Again, it should be kept in mind that the energy return from natural water bodies is generally low compared to that from land features. Thus, all of the water quality related information is contained in a relatively small range of DN levels for each band for the Illinois lakes (Figure 18). This precludes developing trophic indicator estimates that have the accuracies and precisions of the contact-sensed data.

This project is based on the premise that the volume reflectances of water bodies represent distinct characteristics of their optical properties, which are then interpretable in terms of parameters considered important in assessing the trophic state. This concept assumes:

1. Waters with similar optical properties will yield similar spectral responses.

2. Under identical light conditions, the volume reflectance as measured in all LANDSAT bands will generally be lowest for clean water lakes. The inverse is also assumed.

3. Detritus, phytoplankton, suspended solids, and most other natural large particulates are Mie scatters and, therefore, scatter approximately uniformly over the spectrum sensed by the MSS. As the quantity of scattering materials increases, there is a relatively uniform increase in the reflectance curve (Piech and Walker 1971). In other words, the reflectance curve will become higher and flatter as the water becomes more turbid.

4. Substances (e.g., phosphorus) that are not sensible to the MSS, can be sensed indirectly through their effects on parameters that are sensible to the MSS.

5. Shifts in dominant-color reflectance from the blue range toward the red-brown range reflect increases in lake productivity or are associated increases in dissolved color or inorganic turbidity.

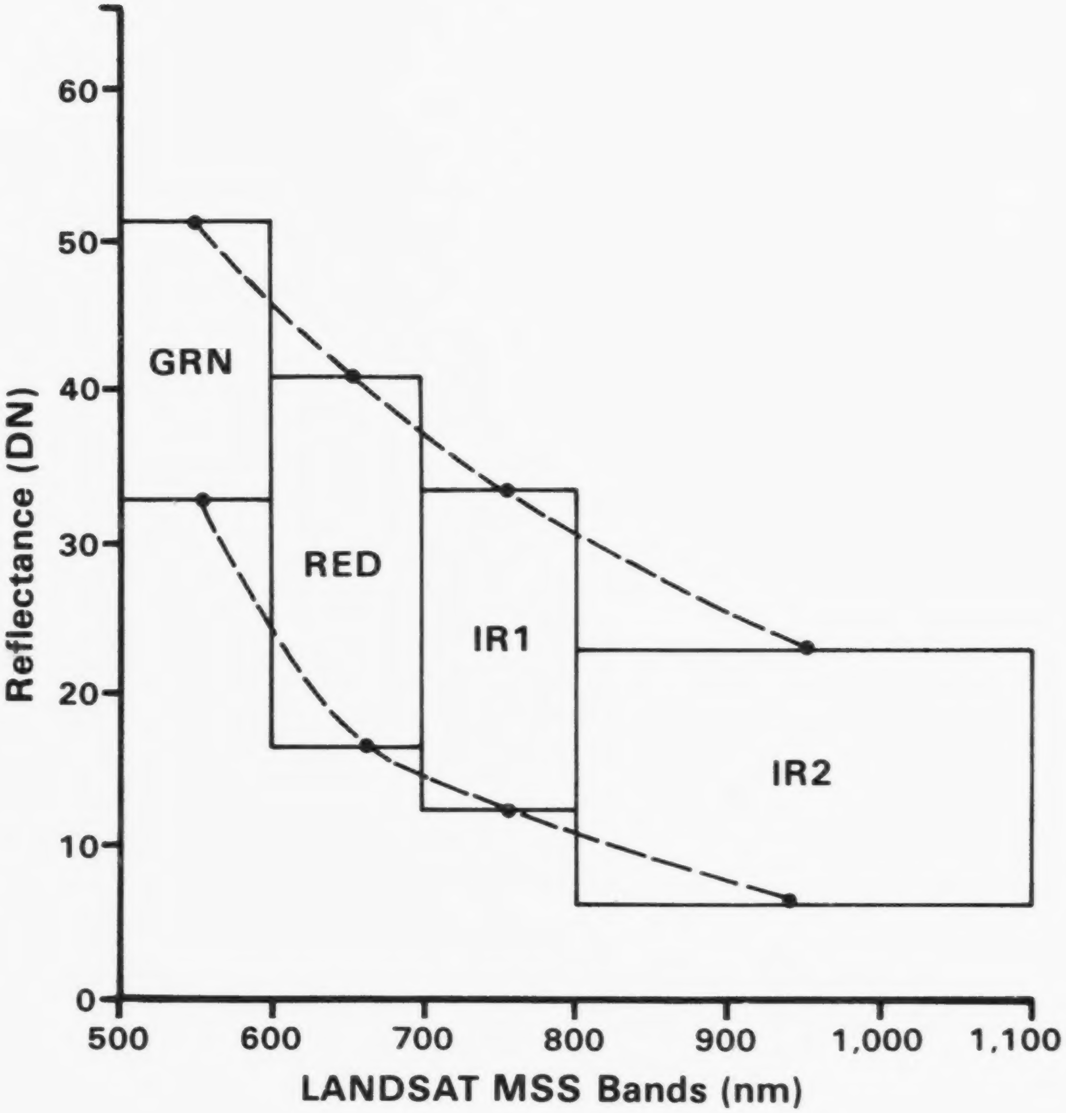


Figure 18. Range of MSS data for 145 Illinois lakes. The data, averages for each lake, were acquired October 14, 15, and 16, 1973, and adjusted to a common date (October 15) using regression analysis.

It should be recognized that the data used for calibration purposes in this project were collected with no thought of their being used in a satellite-related project. Thus, some highly desirable parameters (e.g., total suspended solids, organic particulates, inorganic particulates) were not measured during the time of satellite flyover. In some cases the location of the contact-sensed data stations was less than nominal when viewed through the "eye" of the satellite.

SECTION 6

METHODS

DESIGN OVERVIEW

LANDSAT MSS data can be used to classify lakes and reservoirs with little or no a priori knowledge about the water bodies. However, past experience has shown that the full capabilities inherent in the LANDSAT MSS can only be utilized if the MSS data are used in conjunction with water quality data obtained through contact sensing concurrent or nearly concurrent with satellite flyover. The inclusion of contact-sensed data in the study provides the opportunity to examine the satellite MSS data for statistical relationships (correlations) with specific water quality parameters. If correlations exist, it may then be possible to develop models of practical value for the estimation of trophic indicators and index values.

At this time no generalized model exists that incorporates LANDSAT MSS and contact-sensed data for the estimation of a trophic indicator or index for all inland water bodies at different times of the year; it is necessary to develop regression models specific to a date of LANDSAT coverage. This is accomplished by elucidating the relationships between the MSS data and specific trophic indicators and indices for a relatively small group of benchmark lakes. The resulting regression models are then employed to estimate the magnitudes of indicators and indices for other lakes in the LANDSAT scenes. The need for some contact-sensed data requires that either field crews be dispatched to sample a relatively small number of lakes in the State, in this case Illinois, or that the requisite data be drawn from existing data banks. The second option is attractive for both economic and logistic reasons and was selected for this project.

DATA ACQUISITION

In 1973, the U.S. Environmental Protection Agency's National Eutrophication Survey (NES) sampled 31 Illinois lakes and reservoirs during three periods -- May 7-12, August 7-10, and October 16-19. Details on the sampling procedures and analytical techniques are found in U.S. EPA (1975). The data are stored in the U.S. EPA's STORET system.

Over 100 Illinois lakes were sampled by IEPA during late spring and summer of 1977 (June 15 through August 21). Lake selection criteria (generally adhered to) included a minimal surface area of 40 hectares and public access. The water bodies, well dispersed geographically, were sampled by means of boats. Each was visited once and generally sampled at three sites. Parameters measured included temperature, dissolved oxygen, Secchi depth, alkalinity, conductivity, pH, total suspended solids, volatile suspended solids, total phosphorus, ammonia-nitrogen, and nitrite-nitrate nitrogen. Field observations were recorded and phytoplankton were identified and enumerated. In addition, a problem assessment was conducted for over 350 Illinois lakes under the Section 208 Water Quality Management Program. Existing lake data were collected from various sources, and qualitative evaluations of lake quality and problems were made by persons familiar with the lakes. The details of the 1977 IEPA lake sampling program and the Section 208 lake problems assessment have been published in a separate report (IEPA 1978a).

LANDSAT-1 and LANDSAT-2 cover more than 95 percent of the State of Illinois in three consecutive passes (Figure 19). A search was initiated through the EROS Data Center to determine the availability of LANDSAT MSS scenes for Illinois that were concurrent or nearly concurrent (within a few days) with the NES sampling dates for the 31 Illinois lakes that were to serve as benchmark lakes from which regression model development would be attempted. Past experience (Boland 1976, Rogers 1977) indicates that lakes in the north-central part of the United States are best characterized as to trophic status during the latter part of summer (August to September). Cloud coverage prevented the use of LANDSAT data from the spring and summer NES sampling periods. For the most part, complete LANDSAT coverage was available for Illinois for October 14 to 16, 1973; the NES sampled the lakes from October 16 to 19. Photographic prints and CCT's for 10 LANDSAT scenes were ordered through the EROS Data Center (Table 3). The IR2 image of each scene is displayed as a black-and-white print (Figures 20-30). Each edge of a scene represents a distance of 185 km on the earth's surface; a scene typically covers 34,200 square km. The study lakes are identified by serial number callouts. The names corresponding to the serial numbers are in Table 4.

TABLE 3. LANDSAT MSS SCENES ORDERED FOR ILLINOIS LAKE STUDY

Path Number	Date	Scene Number
24	10-14-73	1448-16023 1448-16030* 1448-16032 1448-16035
25	10-15-73	1449-16082 1449-16084 1449-16091* 1449-16093
26	10-16-73	1450-16140 1450-16142

*NASA-Goddard did not produce the CCT.

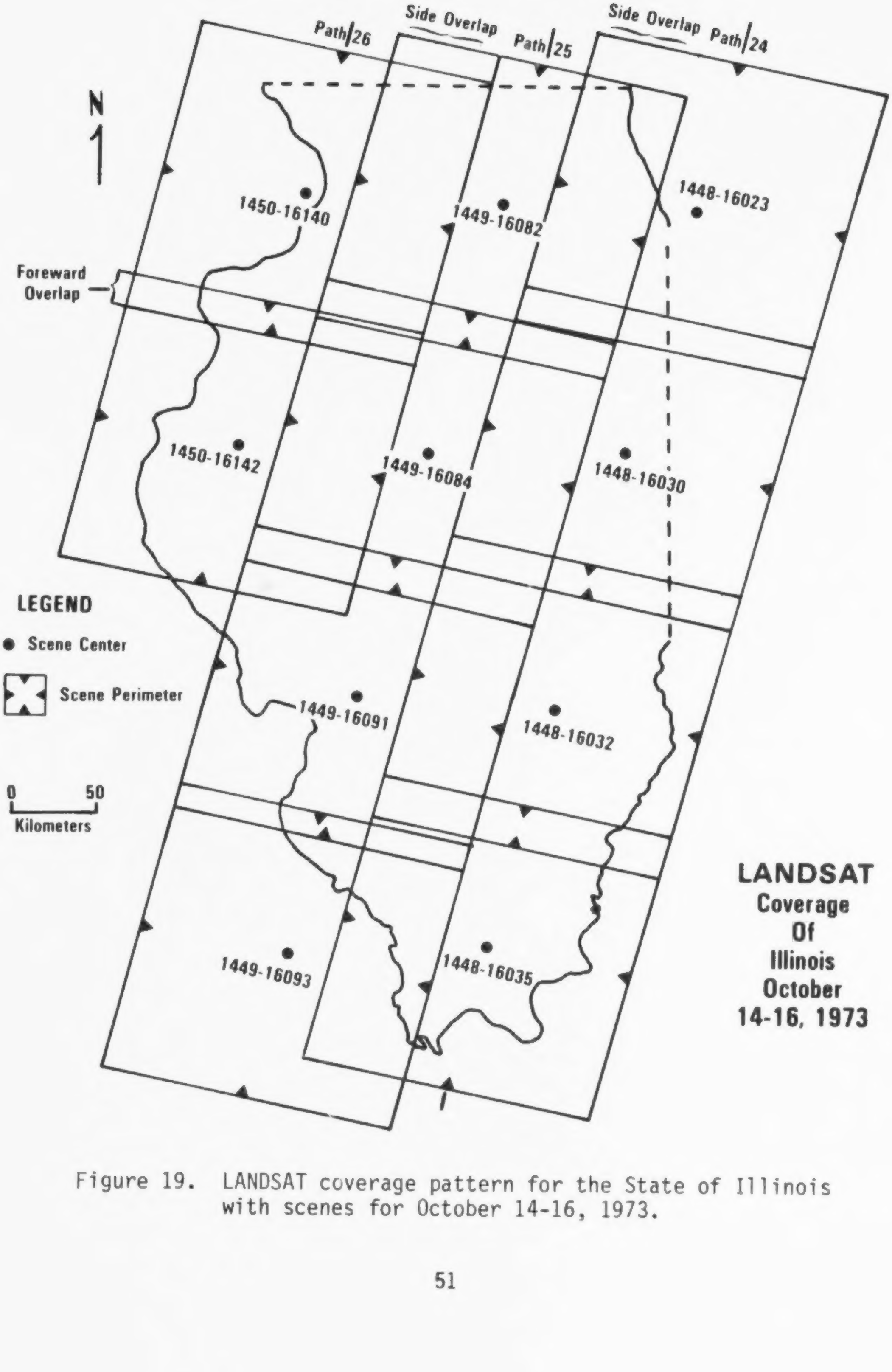
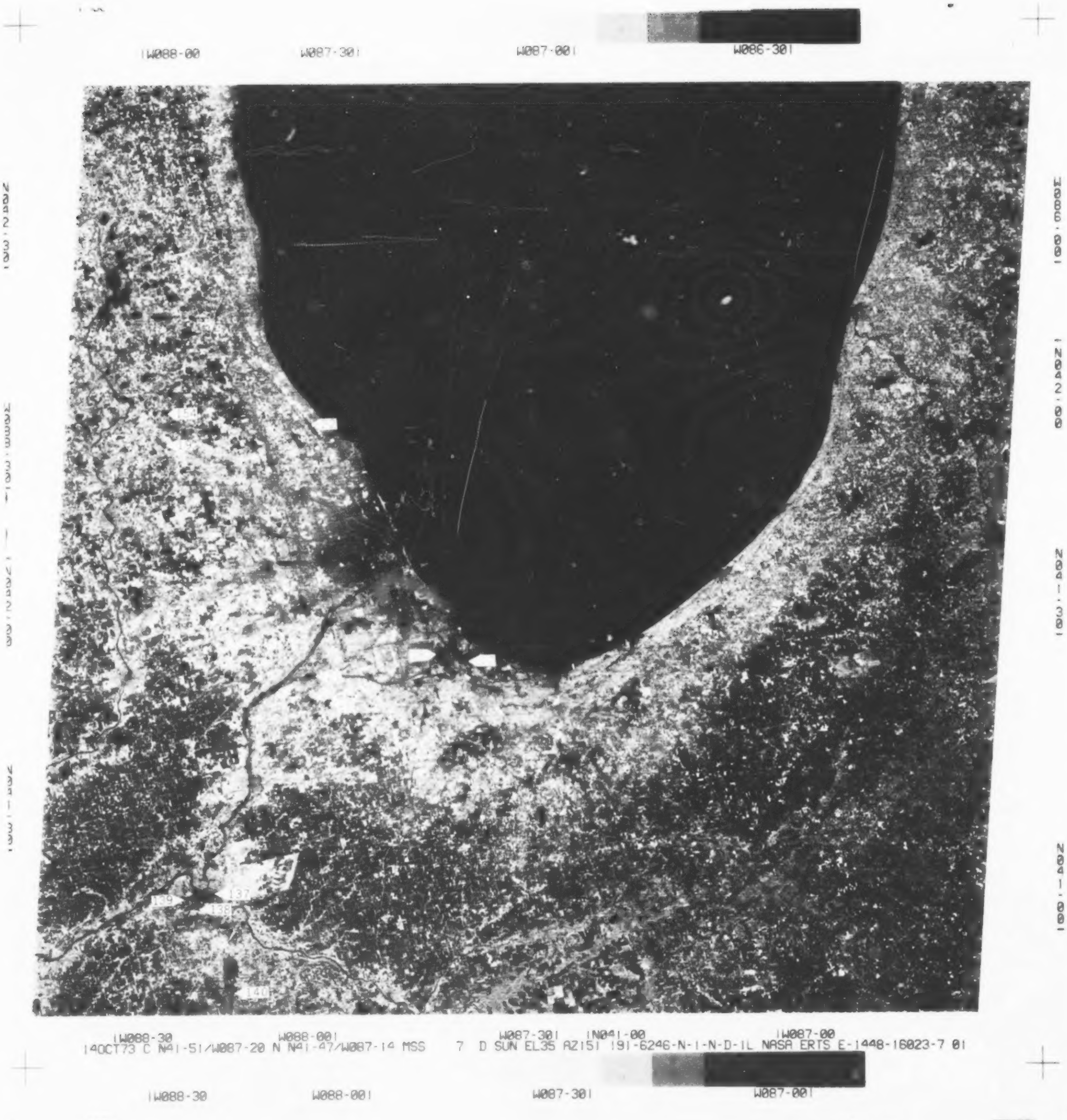
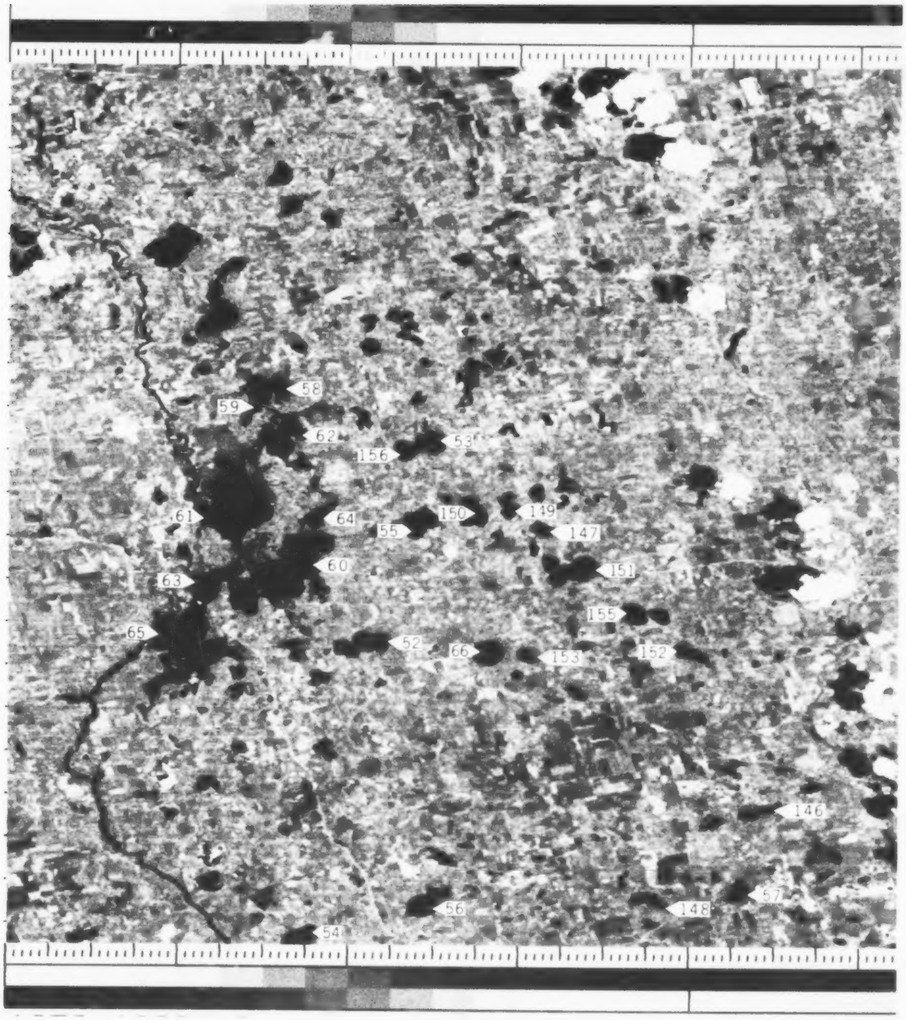

Side Overlap
Side Overlap
Path 26
Path 25
Path 24
N
1450-16140
1449-16082
1448-16023
Foreward Overlap
1450-16142
1449-16084
1448-16030
LEGEND
● Scene Center
Scene Perimeter
1449-16091
1448-16032
0 50
Kilometers
1449-16093
1448-16035
LANDSAT
Coverage
Of
Illinois
October
14-16, 1973

Figure 19. LANDSAT coverage pattern for the State of Illinois with scenes for October 14-16, 1973.



W088-00
W087-30
W087-00
W086-30
W086-00
N042-00
N041-30
N041-00
W088-30
W088-00
W087-30
N041-00
W087-00
14OCT73 C N41-51/W087-20 N N41-47/W087-14 MSS 7 D SUN EL35 AZ151 191-6246-N-1-N-D-1L NASA ERTS E-1448-16023-7 01
137
138
139
140
W088-30
W088-00
W087-30
W087-00

Figure 20. IR2 image of LANDSAT scene 1448-16023 (October 14, 1973). The massive dark object dominating the scene is the southern end of Lake Michigan. Study lakes and reservoirs are identified by serial number callouts. See Table 4 for their names.


58
59
62
156
53
61
64
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150
149
147
60
151
63
155
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152
146
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148
56
54

Figure 21. Enlarged portion of LANDSAT IR2 print containing lakes and reservoirs found in scene 1448-16023.

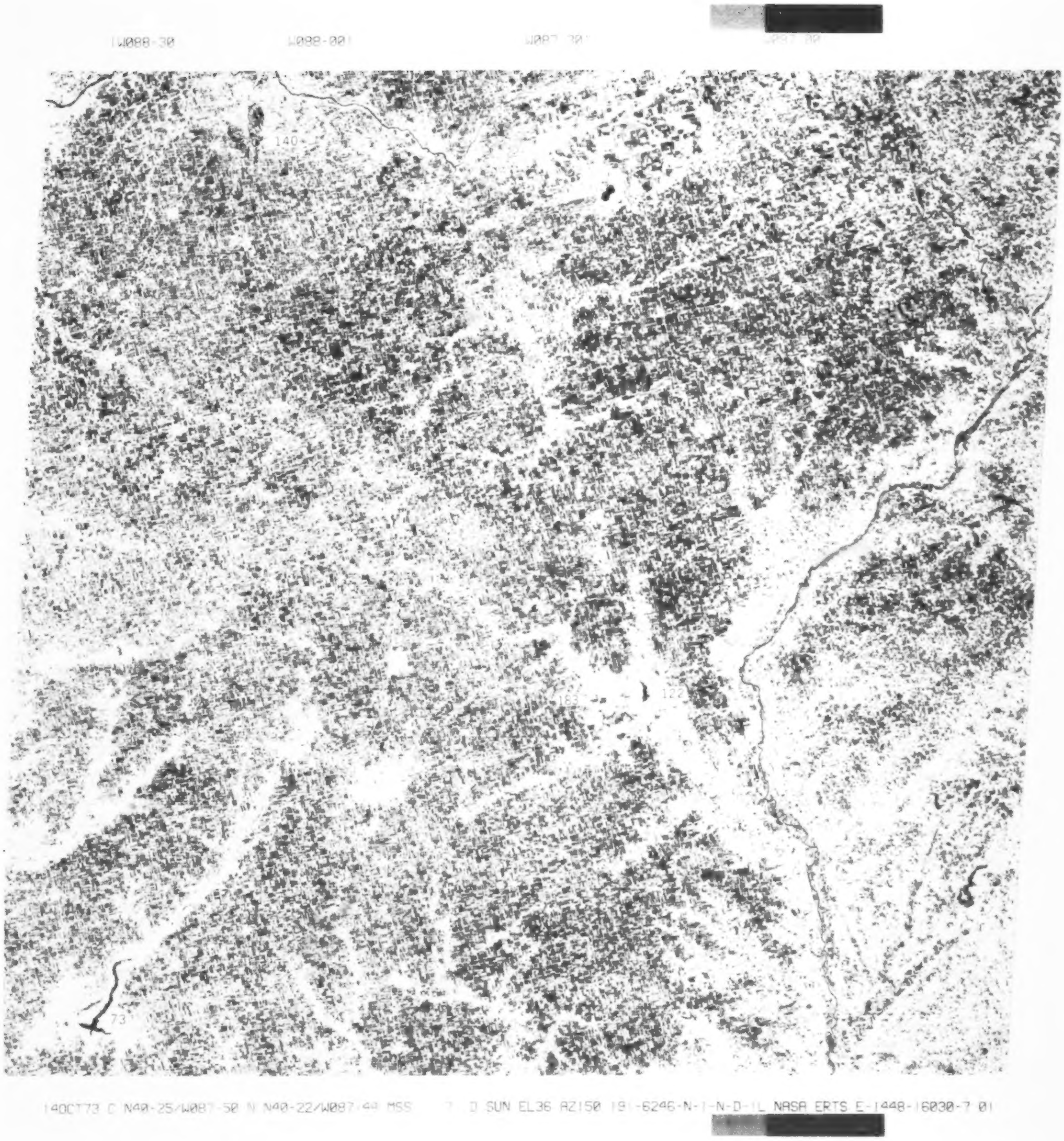

W088-30
W088-00
W087-30
W087-00
140
73
14OCT73 C N40-25/W087-50 N N40-22/W087-44 MSS 7 D SUN EL36 AZ150 191-6246-N-1-N-D-1L NASA ERTS E-1448-16030-7 01

Figure 22. IR2 image of LANDSAT scene 1448-16030 (October 14, 1973). The scene's CCT's were not available from NASA-Goddard.

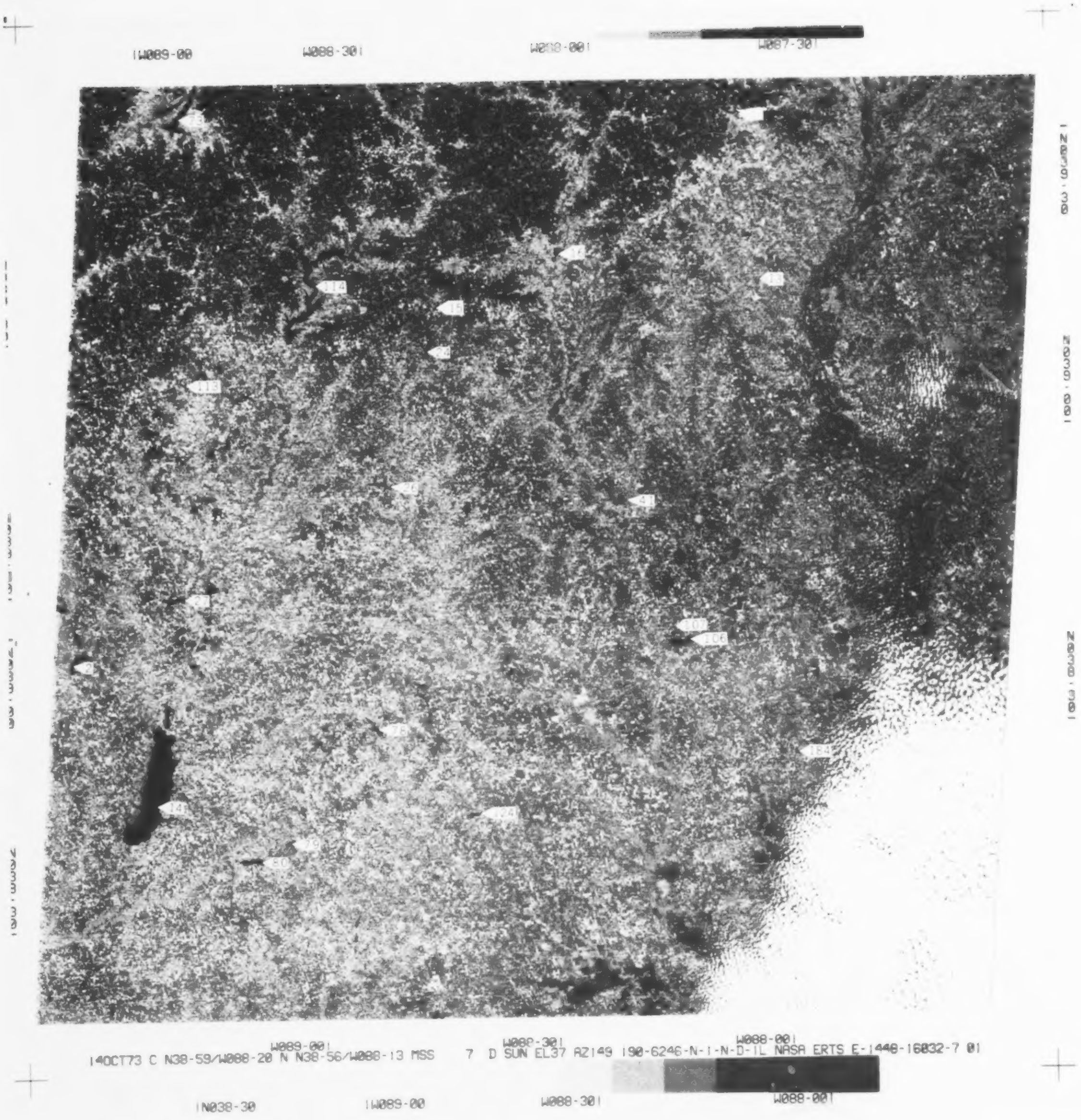

W089-00
W088-30
W088-00
W087-30
N039-30
N039-00
N038-30
W089-00
W088-30
W088-00
14OCT73 C N38-59/W088-20 N N38-56/W088-13 MSS 7 D SUN EL37 AZ149 190-6246-N-1-N-D-1L NASA ERTS E-1448-16032-7 01
N038-30
W089-00
W088-30
W088-00

Figure 23. IR2 image of LANDSAT scene 1448-16032 (October 14, 1973).

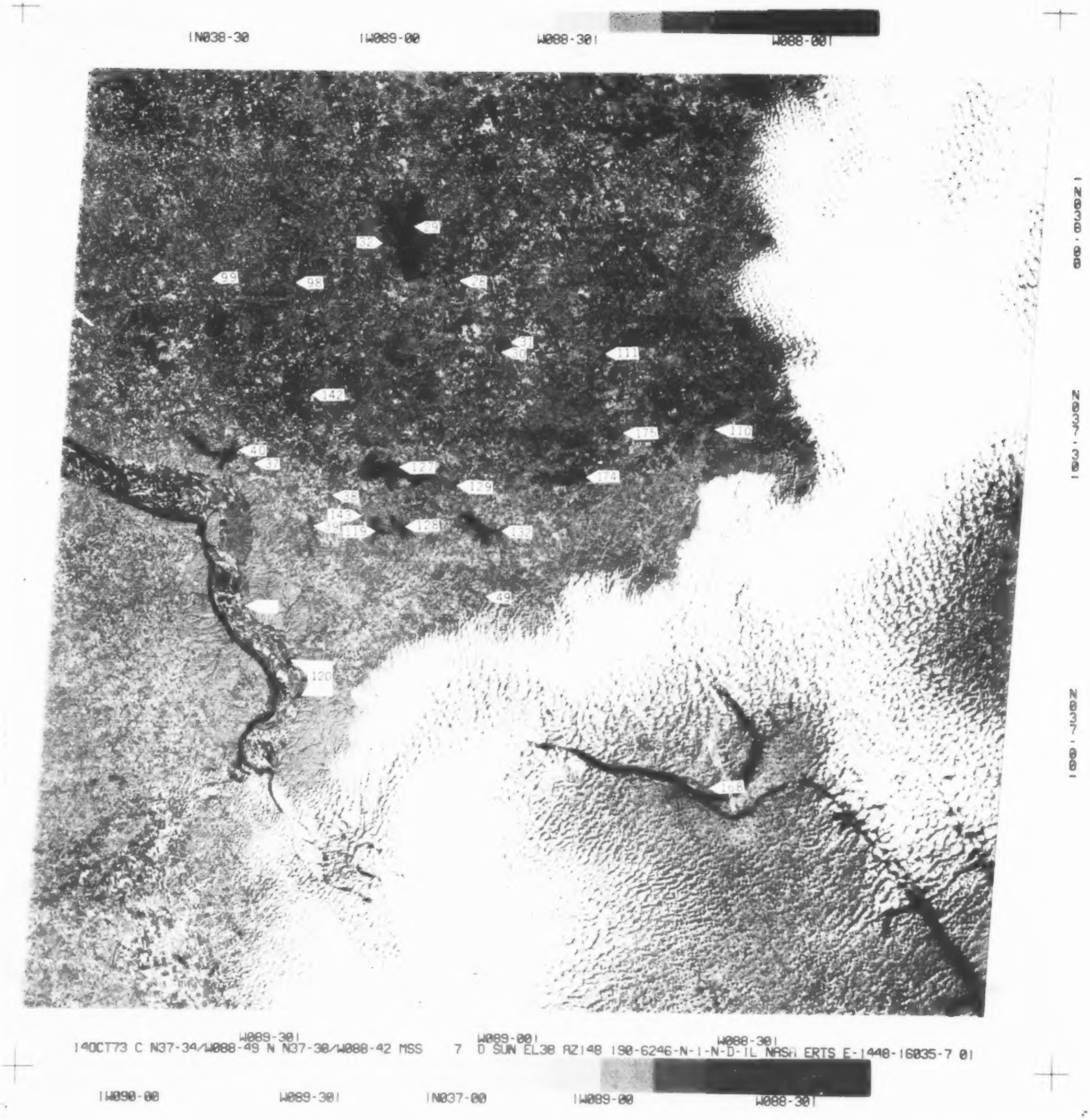

IN038-30
IW089-00
W088-30I
W088-00I
N038-00
N037-30
N037-00
33
29
99
98
28
31
30
111
142
173
110
40
37
127
174
129
48
145
39
115
128
132
49
120
W089-30I
W089-00I
W088-30I
14OCT73 C N37-34/W088-49 N N37-30/W088-42 MSS 7 D SUN EL38 AZ148 190-6246-N-1-N-D-IL NASA ERTS E-1448-16035-7 01
IW090-00
W089-30I
IN037-00
IW089-00
W088-30I

Figure 24. IR2 image of LANDSAT scene 1448-16035 (October 14, 1973). Several Illinois lakes are partially or wholly obscured by clouds.

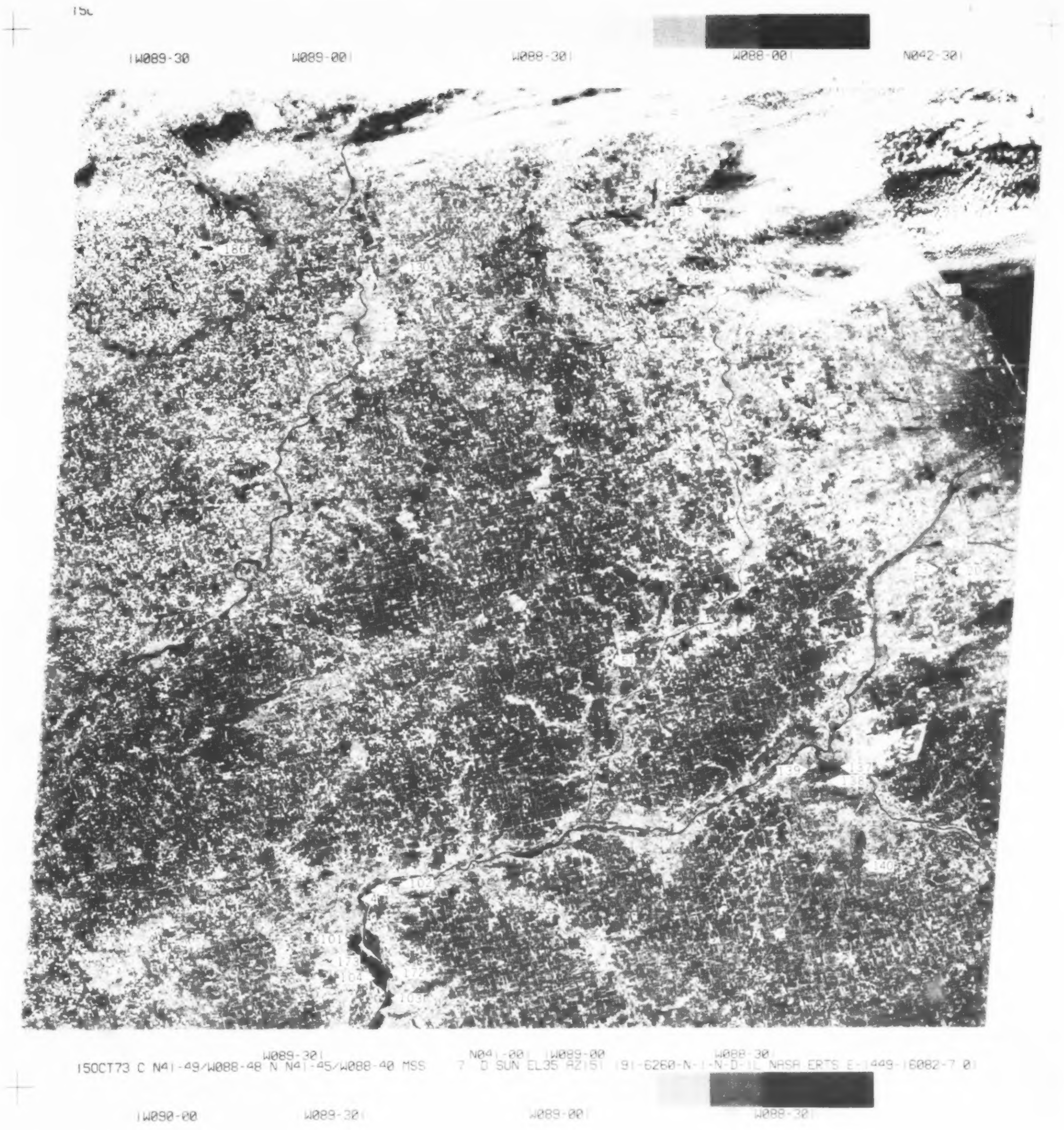

15C
W089-30
W089-00
W088-30
W088-00
N042-30
W089-30
N041-00 W089-00
W088-30
15OCT73 C N41-49/W088-48 N N41-45/W088-40 MSS 7 D SUN EL35 AZ151 191-6260-N-1-N-D-1L NASA ERTS E-1449-16082-7 01
W090-00
W089-30
W089-00
W088-30
166
101
173
164
172
103
139
138
140

Figure 25. IR2 image of LANDSAT scene 1449-16082 (October 15, 1973).

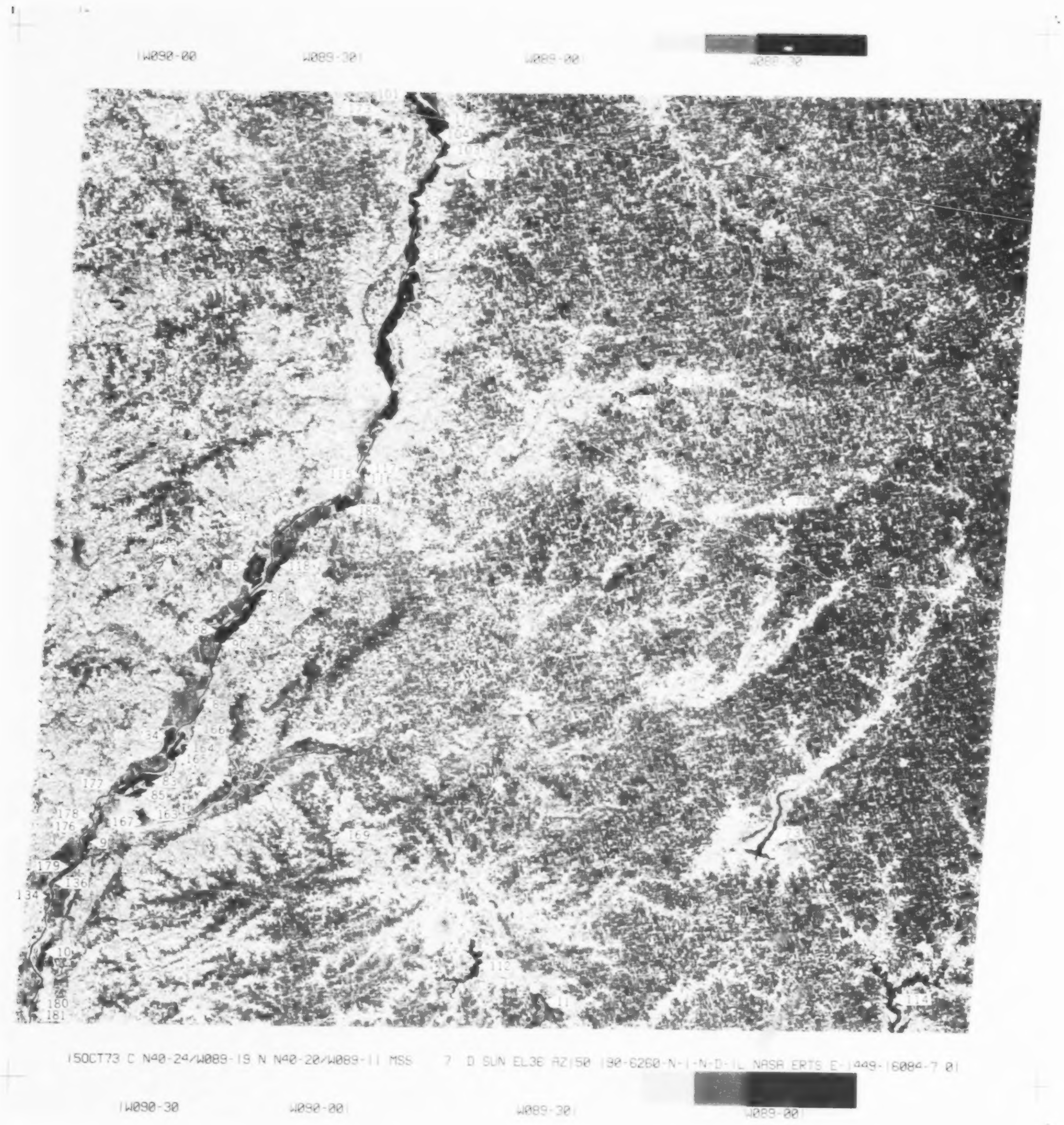

W090-00
W089-30
W089-00
W088-30
15OCT73 C N40-24/W089-19 N N40-20/W089-11 MSS 7 D SUN EL36 AZ150 190-6260-N-1-N-D-1L NASA ERTS E-1449-16084-7 01
W090-30
W090-00
W089-30
W089-00

Figure 26. IR2 image of LANDSAT scene 1449-16084 (October 15, 1973). The CCT's for this scene lacked the necessary internal calibration data. Most of the water bodies were picked up because they appear in forward or side overlap areas of adjacent scenes; seven were dropped.

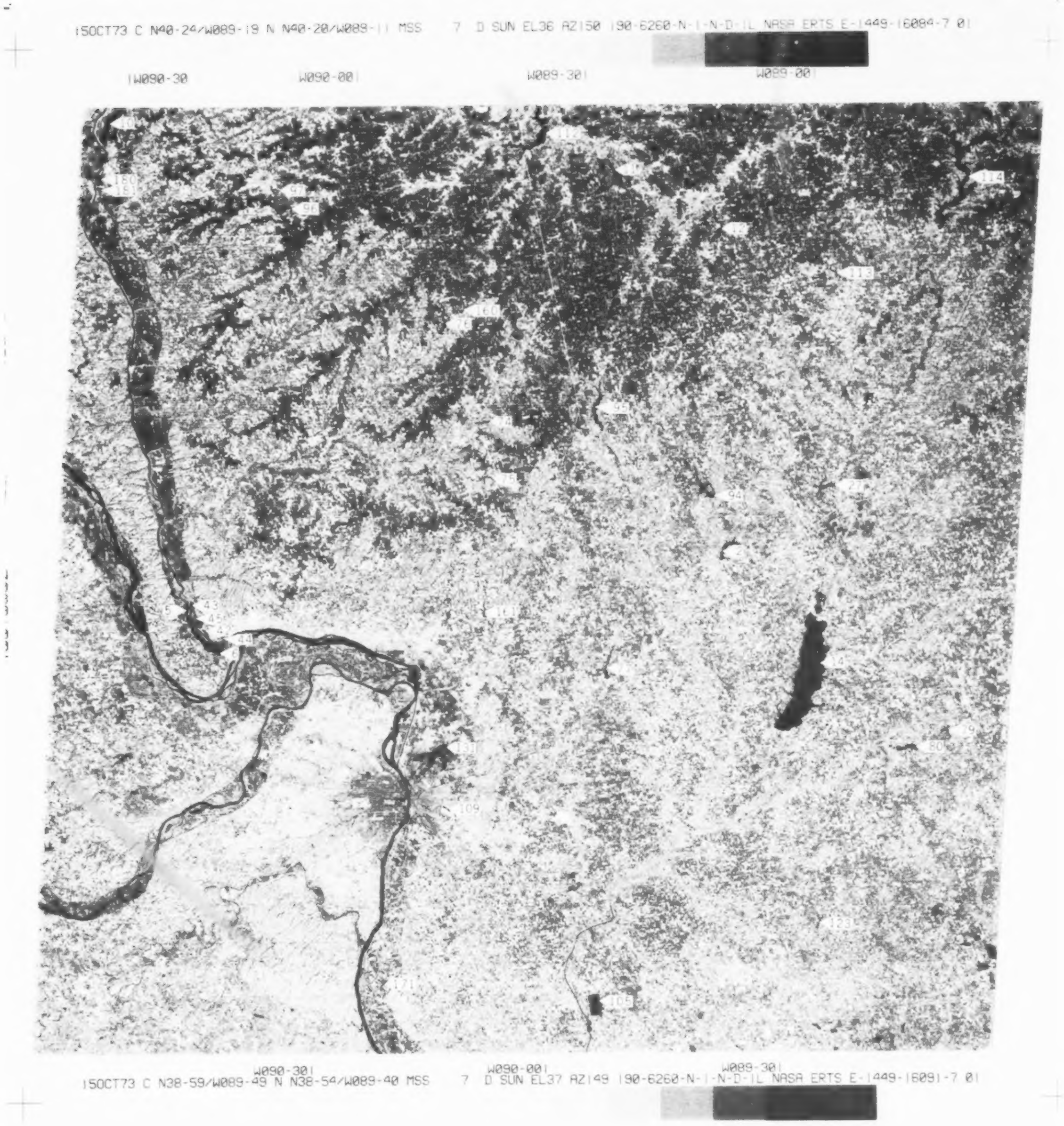

15OCT73 C N40-24/W089-19 N N40-20/W089-11 MSS 7 D SUN EL36 AZ150 190-6260-N-1-N-D-1L NASA ERTS E-1449-16084-7 01
W090-30
W090-001
W089-301
W089-001
W090-301
W090-001
W089-301
15OCT73 C N38-59/W089-49 N N38-54/W089-40 MSS 7 D SUN EL37 AZ149 190-6260-N-1-N-D-1L NASA ERTS E-1449-16091-7 01

Figure 27. IR2 image of LANDSAT scene 1449-16091 (October 15, 1973). The scene's CCT's were not available from NASA-Goddard. Most of the water bodies were picked up because they appear in forward or side overlap areas of adjacent scenes.

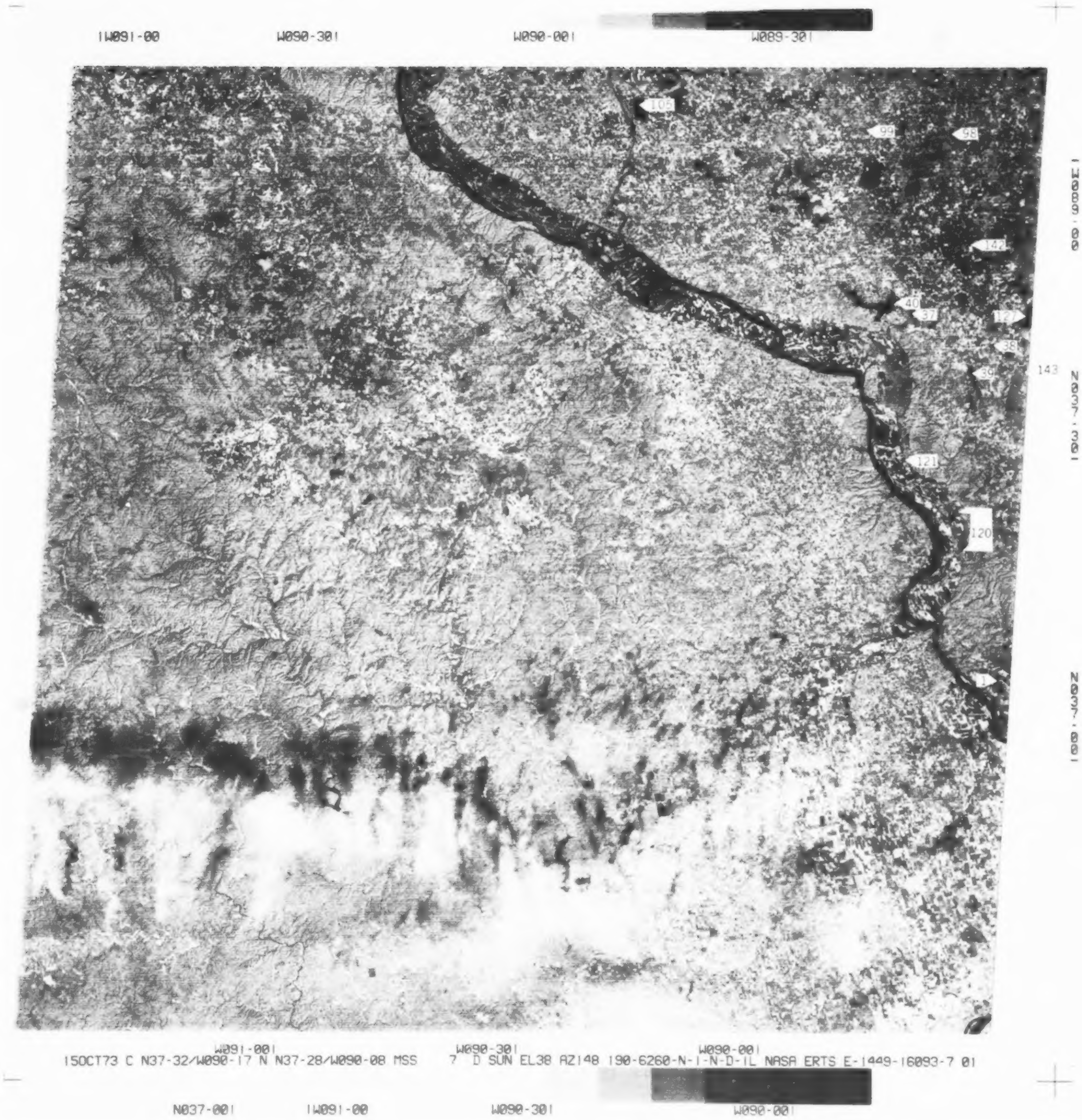

W091-00
W090-30
W090-00
W089-30
102
99
98
142
40
37
127
38
39
143
121
120
1
W089-00
N037-30
N037-00
W091-00
W090-30
W090-00
15OCT73 C N37-32/W090-17 N N37-28/W090-08 MSS 7 D SUN EL38 AZ148 190-6260-N-1-N-D-IL NASA ERTS E-1449-16093-7 01
N037-00
W091-00
W090-30
W090-00

Figure 28. IR2 image of LANDSAT scene 1449-16093 (October 15, 1973).

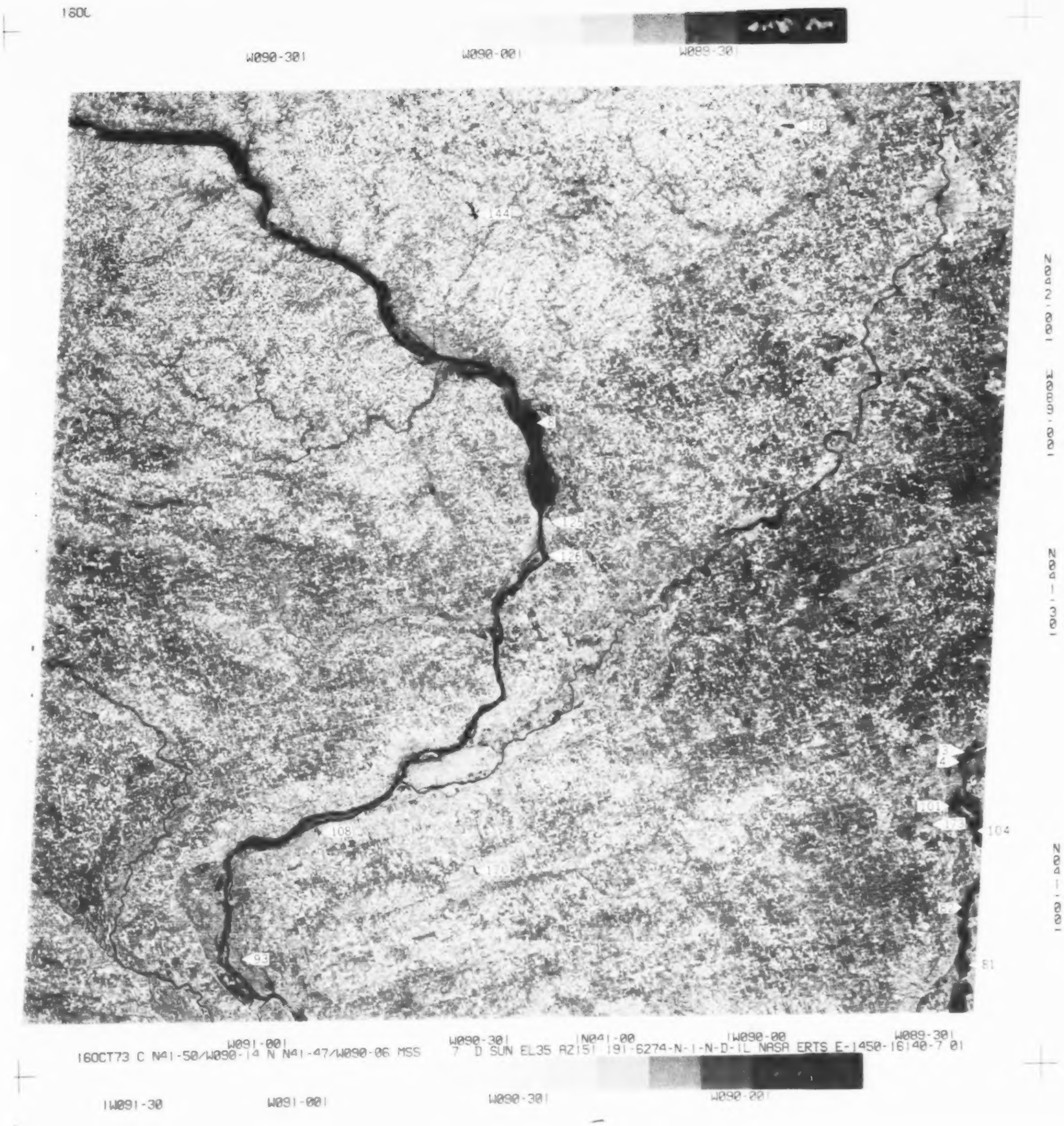

16OL
W090-30
W090-00
W089-30
N042-00
W089-00
N041-30
N041-00
144
128
118
108
93
104
81
W091-00
W090-30
N041-00
W090-00
W089-30
16OCT73 C N41-50/W090-14 N N41-47/W090-06 MSS 7 D SUN EL35 AZ151 191-6274-N-1-N-D-1L NASA ERTS E-1450-16140-7 01
W091-30
W091-00
W090-30
W090-00

Figure 29. IR2 image of LANDSAT scene 1450-16140 (October 16, 1973).

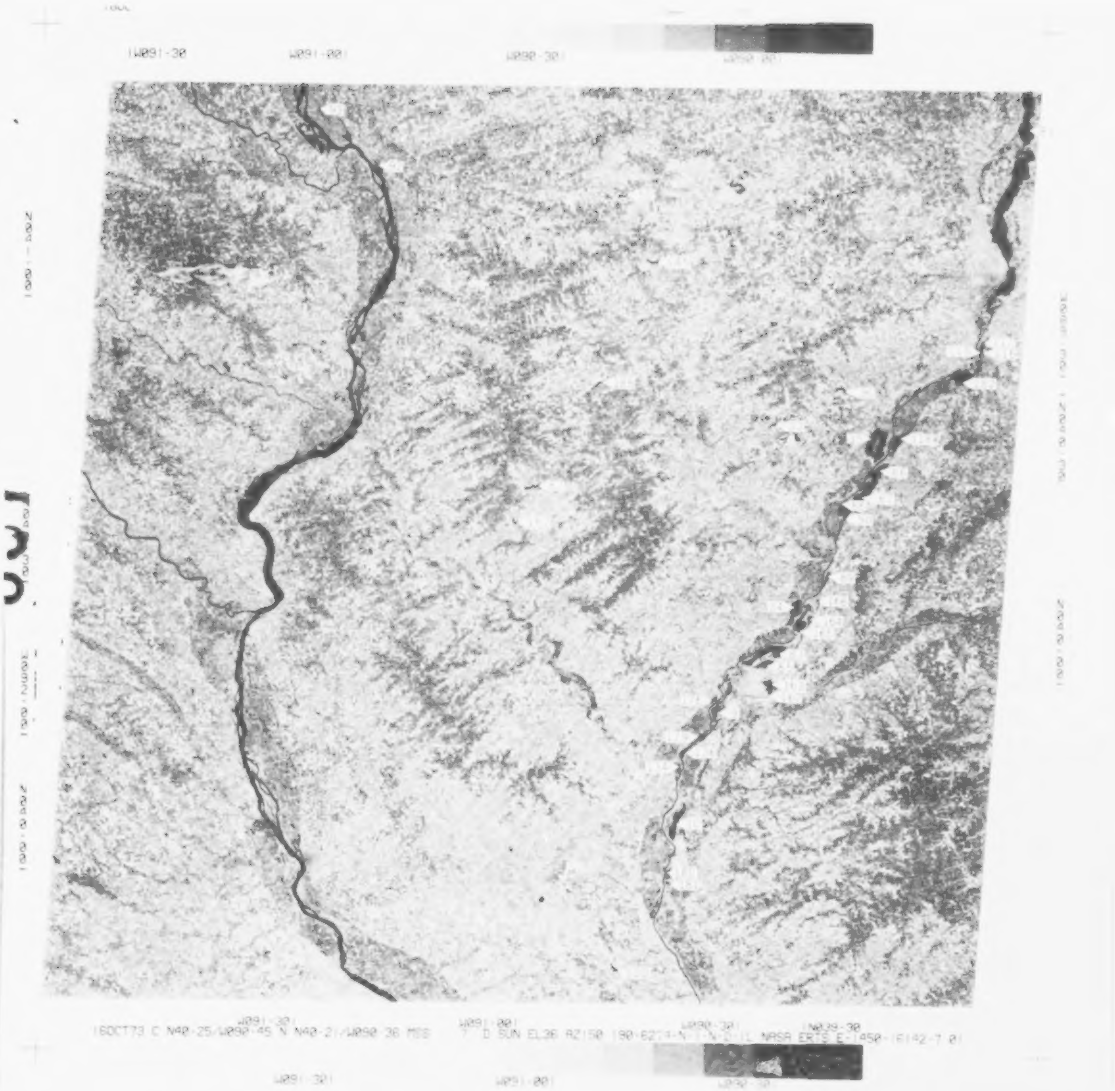

W091-30
W091-00
W090-30
W090-00
16OCT73 C N40-25/W090-45 N N40-21/W090 30 MSS 7 D SUN EL36 AZ150 190-6273-N-1-N-D-1L NASA ERTS E-1450-16142-7 01
W091-30
W091-00
W090-30
W089-30
W091-30
W091-00
W090-30

Figure 30. IR2 image of LANDSAT scene 1450-16142 (October 16, 1973).

TABLE 4. SERIAL LIST OF ILLINOIS WATER BODIES PROPOSED FOR INCLUSION IN TROPHIC CLASSIFICATION PROJECT

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
001	Horseshoe		Alexander	Olive Branch	37-38-32	89-21-30	765	1890
002	Greenville New City (Governor Bond)		Bond	Greenville	38-55-45	89-33-40	314	775
003	DePue	1752	Bureau	DePue	41-18-38	89-19-09	212	524
004	Spring		Bureau	Bureau	41-18-05	89-21-02	106	262
005	Fuller, Taylor, Bundy		Calhoun	Grafton	--	--	61	150
006	Swan		Calhoun	Grafton	38-57-52	90-33-13	949	2345
008	Spring		Carroll	Savanna	42-03-06	90-08-00	1437	3550
009	Sanganois Conservation Area		Cass, Morgan	Beardstown	40-06-00	90-20-00	993	2451
010	Meredosia		Cass, Morgan	Meredosia	39-53-00	90-33-00	685	1692
011	Sangchris	1753	Christian	Kincaid	39-38-40	89-28-50	876	2165
012	Taylorville		Christian	Taylorville	39-31-00	89-15-30	465	1148
013	Lincoln Trail State Park		Clark	Marshall	39-20-33	87-43-03	59	146
014	Carlyle	1706	Clinton, Bond, Fayette	Carlyle	38-43-43	89-16-14	10522	26000
015	Paradise		Coles	Mattoon	39-25-00	88-26-15	71	176
016	Charleston	1708	Coles	Charleston	39-27-30	88-08-25	145	359
017	Wolf		Cook	Chicago	41-40-05	87-31-02	170	419
018	Calumet		Cook	Chicago	41-41-08	87-35-13	648	1600
019	Bakers		Cook	Barrington	42-08-08	88-06-42	53	130
020	McGinnis Slough (Orland)		Cook	Orland Park	41-38-03	87-51-26	127	313

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
021	Saganashkee		Cook	Willow Springs	41-41-28	87-53-04	132	325
022	Skokie Lagoons		Cook	Winnetka	42-07-13	87-46-42	76	190
023	Tampier		Cook	Orland Park	41-38-53	87-54-22	66	163
024	Mattoon		Cumberland	Neoga	39-22-00	88-27-50	310	765
025	Paris Twin		Edgar	Paris	39-38-27	87-41-30	89	220
026	Sara		Effingham	Effingham	39-07-50	88-37-45	237	586
027	Vandalia City	1764	Fayette	Vandalia	39-00-35	89-07-15	267	660
028	Moses		Franklin	Benton	38-01-13	88-52-00	69	170
029	Rend	1735	Franklin, Jefferson	Benton	38-02-35	88-57-05	7650	18900
030	West Frankfort Old		Franklin	West Frankfort	37-53-37	88-48-44	59	146
031	West Frankfort New		Franklin	West Frankfort	37-54-18	88-47-56	87	214
032	Old Ben Mine	1765	Franklin	Sesser	38-06-15	89-00-45	43	106
033	We-Ma-Tuk	1761	Fulton	Fiatt	40-31-56	90-10-14	60	149
034	Anderson		Fulton	Marbletown	40-12-00	90-11-25	552	1364
035	Rice		Fulton	Banner	40-27-30	89-56-55	560	1383
036	Canton		Fulton	Canton	40-43-53	89-58-25	101	250
037	Murphysboro		Jackson	Murphysboro	37-46-52	89-23-02	58	144
038	Carbondale		Jackson	Carbondale	37-41-49	89-13-61	55	136
039	Cedar		Jackson	Carbondale	37-39-52	89-16-58	728	1800
040	Kinkaid		Jackson	Grimsby	37-47-47	89-25-53	1113	2750
041	Sam Parr State		Jasper	Newton	29-01-10	88-07-15	73	180
042	Eagle		Jersey	Grafton	38-59-45	90-33-40	40+	100+
043	Fowler		Jersey	Grafton	39-01-50	90-34-10	94	231
044	Gilbert		Jersey	Grafton	38-57-30	90-31-00	122	300

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
045	Flat, Brushy, Deep,Long		Jersey	Grafton	39-01-00	90-04-15	283+	700+
049	Dutchman		Johnson	Buncombe	37-28-41	88-56-02	48	118
050	Storey	1751	Knox	Galesburg	40-59-20	90-24-30	54	133
051	Holiday	1754	LaSalle	Somonauk	41-36-35	88-39-30	133	328
052	Long	1725	Lake	Long Lake	42-22-33	88-08-10	136	335
053	East Loon	1757	Lake	Antioch	42-27-18	88-04-25	66	163
054	Slocum	1758	Lake	Williams Park (Island Lake)	42-15-34	88-11-20	87	215
055	Cedar	1759	Lake	Lake Villa	42-25-17	88-05-22	115	284
056	Bangs		Lake	Wauconda	42-16-13	88-07-46	120	297
057	Diamond		Lake	Mundelein	42-15-00	88-00-30	60	149
058	Catherine		Lake	Antioch	42-29-08	88-07-04	59	146
059	Channel		Lake	Antioch	42-29-03	88-08-17	129	318
060	Fox	1755	Lake	Fox Lake	42-25-03	88-08-28	692	1709
061	Grass	1756	Lake	Spring Grove	42-25-58	88-09-50	598	1478
062	Marie	1727	Lake	Antioch	42-27-58	88-08-18	209	516
063	Nippersink		Lake	Fox Lake	42-24-08	88-10-43	240	592
064	Petite		Lake	Lake Villa	42-25-47	88-07-39	67	165
065	Pistakee	1733	Lake, McHenry	Fox Lake	42-23-18	88-12-22	829	2048
066	Round		Lake	Round Lake	42-21-41	88-04-33	87	215
067	Spring		McDonough	Macomb	40-30-30	90-43-25	112	277
068	Crystal		McHenry	Crystal Lake	42-14-04	88-21-27	92	228
069	Wonder	1750	McHenry	Wonder Lake	42-24-00	88-20-40	295	729
070	Dawson		McLean	LeRoy	40-24-30	88-43-30	61	150
071	Bloomington	1703	McLean	Bloomington	40-39-43	88-56-20	257	635
072	Evergreen		McLean, Woodford	Bloomington	40-38-36	89-02-30	283	700

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
073	Decatur	1714	Macon	Decatur	39-49-30	88-57-11	1252	3093
074	Carlinville		Macoupin	Carlinville	39-14-30	89-52-00	68	168
075	Gillespie New		Macoupin	Gillespie	39-08-20	89-05-20	84	207
076	Otter		Macoupin	Girard	39-24-12	89-54-30	310	765
077	Highland(Silver)	1740	Madison	Highland	38-46-05	89-41-50	223	550
078	Stephen A. Forbes		Marion	Omega	38-43-13	88-45-12	213	525
079	Centralia		Marion	Centralia	38-33-24	89-00-12	182	450
080	Raccoon	1762	Marion	Centralia	38-32-40	89-06-15	374	925
081	Marshall County Public Hunting & Fishing Area (Babb, Sawyer, Wightman)		Marshall	Lacon	41-00-53	89-25-35	1035	2557
082	Goose		Marshall	Sparland	41-15-45	89-14-45	526	1300
083	Chain, Ingram, Sangamon, Stafford, Stewart, Snicarte		Mason		--	--	1458+	3600+
085	Crane		Mason	Snicarte	40-07-15	90-16-40	306	756
086	Clear		Mason	Liverpool	40-25-00	89-57-00	592	1463
087	Chautauqua		Mason	Havana	40-22-30	90-01-00	1442	3562
088	Liverpool		Mason	Liverpool	40-22-10	90-02-25	63	155
089	Matanzas		Mason	Havana	40-15-00	90-06-00	146	361
090	Quiver		Mason	Havana	40-20-08	90-02-30	165	407
091	Mermet Conservation Area		Massac	Mermet	37-15-28	88-50-47	183	452
092	Keithsburg National Wildlife Refuge		Mercer	Keithsburg	--	--	72	178

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
093	Swan		Mercer	New Boston	41-14-35	91-03-35	49	120
094	Coffeen	1711	Montgomery	Coffeen	39-02-15	89-23-45	420	1038
095	Lou Yaeger	1726	Montgomery	Litchfield	39-11-15	89-35-58	514	1269
096	Jacksonville		Morgan	Jacksonville	39-40-15	90-12-45	193	477
097	Mauvaise Terre		Morgan	Jacksonville	39-42-35	90-12-45	70	172
098	DuQuoin		Perry	DuQuoin	38-04-00	89-13-30	99	244
099	Pinckneyville		Perry	Pinckneyville	38-06-00	89-24-10	67	165
100	New Pittsfield		Pike	Pittsfield	--	--	98	241
101	Goose		Putnam, Bureau	Henry	--	--	1143	2823
102	Turner		Putnam	Granville	41-18-47	89-15-00	122	300
103	Sawmill		Putnam		--	--	255	630
104	Senachwine		Putnam	Henry	41-10-00	89-21-00	1346	3324
105	Baldwin	1763	Randolph, St. Clair	Baldwin	38-12-25	89-51-55	796	1967
106	Olney East Fork		Richland	Olney	38-45-08	88-04-15	379	935
107	Olney New		Richland	Olney	38-47-04	88-03-49	56	138
108	George		Rock Island	Andalusia	41-25-11	90-49-50	68	167
109	Frank Holten State Park Pond Three (Grand Marais)		St. Clair	East St. Louis	38-34-48	90-05-13	54	133
110	Glen O. Jones		Saline	Equality	37-41-00	88-23-00	43	105
111	Harrisburg		Saline	Raleigh	38-50-45	88-35-18	85	209
112	Springfield	1742	Sangamon	Springfield	39-41-14	89-38-58	1630	4025
113	Pana		Shelby, Christian	Pana	39-21-00	89-01-25	89	220
114	Shelbyville	1739	Shelby, Moultrie	Shelbyville	39-24-30	88-46-30	4452	11000

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area	
							(Hectares)	(Acres)
115	Lake of the Woods		Tazewell	Pekin	40-35-11	89-38-52	44	108
116	Pekin		Tazewell	Pekin	40-35-00	89-35-15	43	105
117	Worley		Tazewell	Pekin	40-35-49	89-38-05	105	259
118	Spring		Tazewell	Manito	40-30-59	89-48-30	520	1285
119	Little Grassy		Williamson, Jackson	Makanda	37-38-12	89-07-45	405	1000
120	Lyerla-Autumnal Flooding		Union	Reynoldsville	--	--	105	259
121	LaRue-Pine Hills Ecological Area		Union	LaRue	--	--	382	943
122	Vermilion	1748	Vermilion	Danville	40-09-24	87-39-03	246	608
123	Washington County		Washington	Nashville	38-16-20	89-21-30	119	295
124	Sam Dale State		Wayne	Johnsonville	38-32-29	88-35-00	79	194
125	Cattail		Whiteside	Fulton	41-51-55	90-08-30	47	115
126	Sunfish		Whiteside	East Clinton	--	--	72	178
127	Crab Orchard	1712	Williamson	Carterville	37-43-50	89-08-30	2819	6965
128	Devil's Kitchen		Williamson	Marion	37-38-06	89-06-18	328	810
129	Marion		Williamson	Marion	37-40-49	88-57-26	89	220
130	Pierce		Winnebago	Rockford	42-20-55	88-58-50	66	163
131	Horseshoe	1766	Madison	Granite City	38-41-01	90-06-48	853	2107
132	Lake of Egypt		Johnson, Williamson	Goreville	37-37-15	88-56-43	931	2300
134	Big		Brown	Versailles	39-58-15	90-31-00	106	262
135	Mud, Sand		Calhoun	Gilead	39-08-12	90-41-07	110	271
136	Lily		Cass	Beardstown	--	--	115	285
137	Commonwealth Edison-Dresden Nuclear		Grundy, Will	Morris	41-21-30	88-15-00	526	1300

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
138	Coal City Recreation Club		Grundy	Coal City	--	--	129	318
139	Goose(Village Club)		Grundy	Morris	--	--	109	268
140	South Wilmington Fireman's Beach and Park Club		Grundy	E. Brooklyn	--	--	41	101
142	Snyder's Hunting Club		Jackson	Elkville	37-54-17	89-10-50	81	200
143	Spring Arbor		Jackson	Carbondale	37-38-48	89-10-09	41	100
144	Apple Canyon		Jo Daviess	Apple River	42-26-00	90-10-00	194	480
145	Bracken		Knox	Galesburg	40-51-30	90-21-00	70	172
146	St. Mary's		Lake	Mundelein	42-16-57	87-59-44	41	101
147	Sand		Lake	Lindenhurst	42-24-33	88-02-31	47	115
148	Countryside		Lake	Mundelein	42-15-20	88-30-15	57	141
149	Crocked		Lake	Lake Villa	42-25-22	88-02-31	53	130
150	Deep		Lake	Lake Villa	42-55-22	88-04-01	81	200
151	Fourth		Lake	Lake Villa	42-23-27	88-01-29	126	310
152	Gages		Lake	Grayslake	42-21-03	87-59-52	56	139
153	Highland (Old Taylor's)		Lake	Grayslake	42-31-47	88-03-52	45	110
154	Zurich		Lake	Lake Zurich	42-11-45	88-06-27	92	228
155	Third		Lake	Grayslake	42-22-31	88-30-47	64	157
156	West Loon		Lake	Antioch	42-27-13	88-05-03	66	163
157	Argyle		McDonough	Colchester	40-27-15	90-47-30	38	95
158	Griswold		McHenry	Island Lake	42-17-17	88-13-16	57	141
159	McCullom		McHenry	McHenry	42-21-42	88-17-32	99	245
160	Sunset		Macoupin	Girard	39-26-12	89-51-20	59	146

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area (Hectares)	Surface Area (Acres)
161	Holiday Shores		Madison	Edwardsville	38-55-05	89-56-19	174	430
162	Wildwood		Marshall	Vorna	41-04-16	89-16-25	89	220
163	Mound		Mason	Snicarte	40-07-00	90-22-00	140	345
164	Moscow		Mason	Bath	40-10-35	90-09-45	104	258
165	Jack, Swan, Grass		Mason	Bath	40-11-30	90-10-45	673	1662
166	Bath		Mason	Bath	40-07-00	90-09-45	56	138
167	Otter		Mason	Snicarte	40-04-00	90-16-45	117	289
168	Kinneman		Massac	Unionville	37-04-56	88-32-27	42	103
169	Petersburg		Menard	Petersburg	39-59-15	89-50-55	77	191
170	Fyre		Mercer	Sherrard	41-18-00	90-19-30	67	165
171	Moredock		Monroe	Valmeyer	38-19-19	90-18-40	55	135
172	Swan		Putnam	Henry	41-10-00	89-14-00	115	285
173	Thunderbird		Putnam	Putnam	41-12-21	89-26-53	46	113
174	Open (Marshy)		Saline	Stonefort	--	--	222	548
175	Sahara Coal Company		Saline	Carrier Mills	--	--	47	115
176	Big		Schuyler	Frederick	40-04-30	90-24-45	44	108
177	Long		Schuyler	Browning	40-08-30	90-20-00	45	111
178	Sugar Creek (Curry)		Schuyler	Frederick	40-05-40	90-23-50	49	121
179	Yorky		Schuyler	Beardstown	--	--	188	465
180	Upper Smith (Atkinson)		Scott, Morgan	Naples	39-47-00	90-35-30	112	277
181	Lower Smith		Scott	Naples	39-46-15	90-35-30	51	125
182	Powerton Cooling		Tazewell	Pekin	--	--	577	1426
183	Vermilion Fishing Club		Vermilion	Oakwood	--	--	43	105

(continued)

TABLE 4. (continued)

Serial Number	Name of Water Body	STORET Number	County	Nearby Town	Latitude (North)	Longitude (West)	Surface Area	
							(Hectares)	(Acres)
184	Mesa		Wabash	Lancaster	38-31-43	87-51-37	41	102
185	Little Swan		Warren	Avon	40-40-00	90-32-00	101	250
186	Summerset		Winnebago	Durand	42-27-10	89-23-40	115	285

Figure 31 depicts the geographic distribution of the water bodies in a county framework.

NASA-Goddard experienced difficulty in generating the CCT's and was ultimately unable to provide the CCT's for two scenes (1448-16030 and 1449-16091). In addition, the CCT's for scene 1449-16084 arrived without internal calibration data; this scene was eventually dropped from consideration.

DATA PROCESSING

Multispectral Data Processing

LANDSAT MSS data are available from EROS in photographic and digital (i.e., CCT) formats. Data relating to lacustrine trophic state can be extracted from both products. However, in water-related studies the use of digital data is preferred to avoid the uncertainties introduced when digital data are coded into a photographic product and then requantified through microdensitometry. The digital approach, selected for this project, permits the rapid determination of picture element (pixel) counts and descriptive statistics, and the application of a multitude of digital image enhancement, processing, and classification techniques.

The LANDSAT CCT's were processed in the Image Processing Laboratory (IPL) at NASA's Jet Propulsion Laboratory (JPL) using an IBM 360/65 and associated software and peripherals. The system was operated in two modes, batch and interactive.

MSS Data Preprocessing--

Prior to attempting classifications of any sort, certain multispectral data processing procedures must be implemented. Preprocessing functions, applied to MSS data, are employed to make corrective changes for both cosmetic purposes and geometric reasons. The cosmetic processing corrects for line dropouts, slipped or missing lines, and other obvious defects in the imagery. In terms of geometric corrections, the LANDSAT computer-compatible tapes (CCT's) are not in a format compatible to the processing approaches used in the IPL. The CCT's, as received from the EROS Data Center, have the data for the four MSS bands interleaved. The IPL software program, VERTSLOG, separates the interleaved data and creates a separate image for each band. Next, various geometric corrections are made to compensate for mirror velocity changes and panorama. The data are resampled to create an instantaneous field of view (IFOV) approximating 80 meters. In addition, the MSS data are expanded from seven bits of precision in the green (GRN), red (RED), and near infrared-one (IR1) bands, and six bits in the near infrared-two (IR2) band, to eight bits of precision resulting in 256 digital number (DN) levels (0-255).

Lake Extraction Methodology--

The primary thrust of this task is water quality monitoring and lake classification. The project is not concerned with land use or land-use practices as they relate to water quality at this time. The image-processing

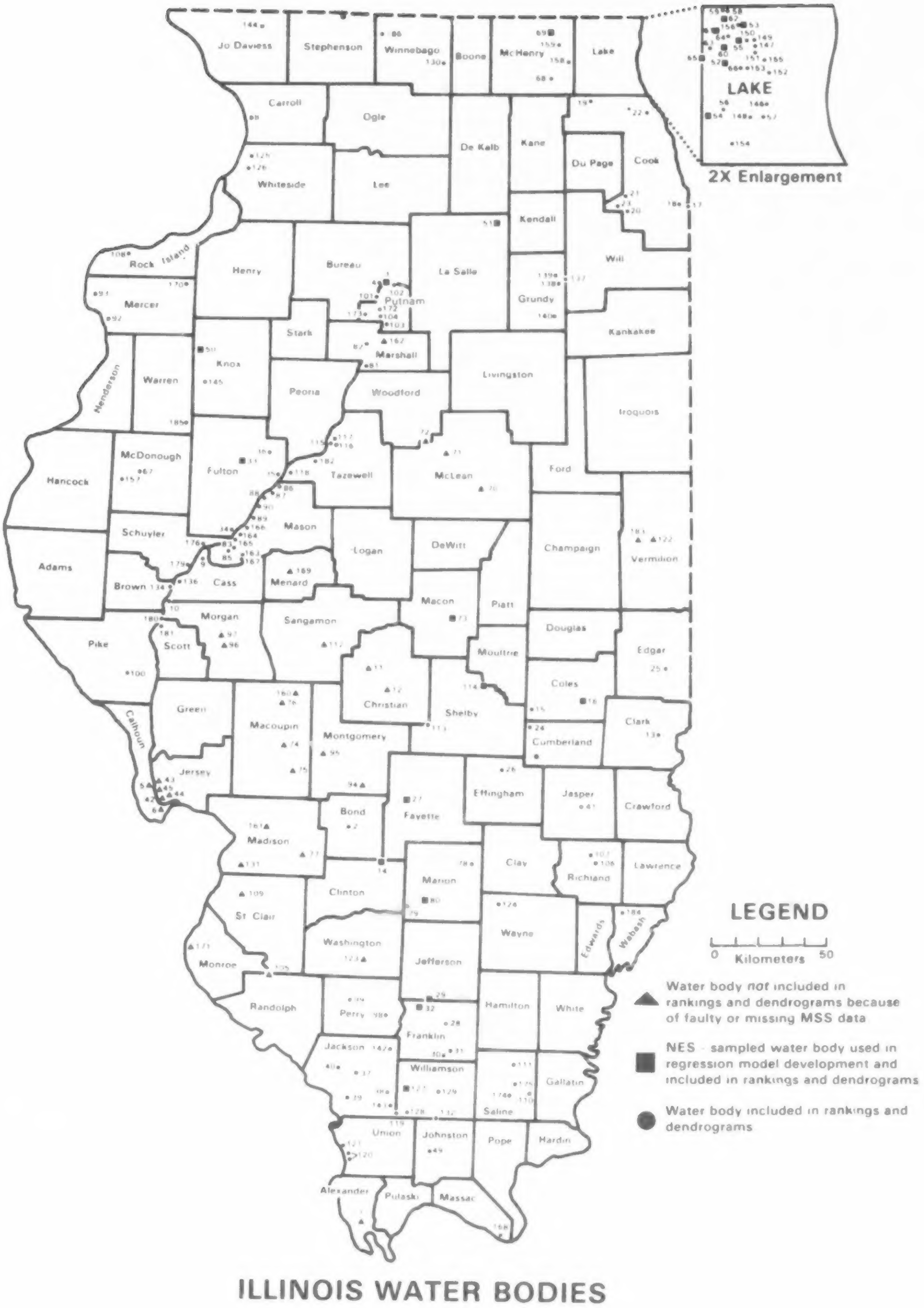

ILLINOIS WATER BODIES
LAKE
2X Enlargement
LEGEND
0 Kilometers 50
▲ Water body *not* included in rankings and dendrograms because of faulty or missing MSS data
■ NES - sampled water body used in regression model development and included in rankings and dendrograms
● Water body included in rankings and dendrograms
Jo Daviess
Stephenson
Winnebago
Boone
McHenry
Lake
Carroll
Ogle
De Kalb
Kane
Du Page
Cook
Whiteside
Lee
Kendall
Rock Island
Henry
Bureau
La Salle
Will
Mercer
Putnam
Grundy
Stark
Marshall
Kankakee
Knox
Henderson
Warren
Peoria
Woodford
Livingston
Iroquois
McDonough
Hancock
Fulton
Tazewell
McLean
Ford
Schuyler
Mason
Logan
DeWitt
Champaign
Vermilion
Adams
Brown
Cass
Menard
Macon
Piatt
Pike
Morgan
Scott
Sangamon
Douglas
Edgar
Moultrie
Christian
Coles
Calhoun
Greene
Macoupin
Montgomery
Shelby
Clark
Cumberland
Jersey
Effingham
Jasper
Crawford
Bond
Fayette
Madison
Clay
Richland
Lawrence
Clinton
Marion
St Clair
Wayne
Edwards
Wabash
Washington
Monroe
Jefferson
Randolph
Perry
Hamilton
White
Franklin
Jackson
Williamson
Gallatin
Saline
Union
Johnston
Pope
Hardin
Alexander
Pulaski
Massac

Figure 31. Geographic distribution of the Illinois water bodies in a county framework.

techniques used early in this project were designed to extract and manipulate MSS pixels, representing surface water, in a batch mode of operation. The extraction procedure, explained in detail by Blackwell and Boland (1975), is outlined below.

Upon completion of the previously described preprocessing functions, a hard-copy image is generated from the rescaled band 7 (IR2) data (e.g., Figure 24). A candidate lake is selected from the scene, and a polygon is constructed around it. The polygon's coordinates are input to the computer system, and four new images, each an MSS band rendition of the subsection of the LANDSAT scene, are generated depicting water body, surrounding terrain, and a histogram of DN values for all of the pixels comprising the subsection (Figure 32).

Through inspection, and after comparative testing, it has been determined that an IR2 DN value of 28 provides good segregation of water and land features. A binary mask is developed from the IR2-extracted lake image by setting IR2 data values between 0 and 28 equal to 1 and all other IR2 DN values (29 to 255) equal to 0. The binary mask, in which water pixel values equal 1 and nonwater pixel values equal 0, is then used to eliminate all but water-related features in the subscene. Multiplication of each MSS band subsection image [4 (GRN), 5 (RED), 6 (IR1), 7 (IR2)] pixel by its IR2 binary-mask counterpart produces an image for each band. If processed correctly, the images will represent only pixels containing water-related information. Figure 33 is an example of the image produced by masking each subscene image with its counterpart IR2 binary mask.

Some final editing is required to eliminate rivers, streams, and other water-related features not considered to be part of the lake proper. Once editing is completed, listings are generated of pixel counts, DN histograms, and mean DN values for each band for the entire water body, along with their associated standard deviations. The water body's mean DN values (Appendix Table A-1) for each of the four LANDSAT MSS spectral bands are used for model development and classification purposes.

Interactive Lake Extraction Methodology--

The lake extraction methodology previously described was originally designed to handle a relatively small number of lakes in a batch processing computer mode. The method, though accurate, was inherently slow since the image-processing analyst necessarily had to wait for products before continuing with the next phase of processing. However, during the course of this project, the capability for interactive image processing at JPL's Image Processing Lab was developed. The interactive system enabled analysts associated with this task to develop and utilize a series of three programs that effectively reduced the time to isolate a lake, increased the accuracy of the water-detection scheme, and output a statistical and surface area listing for any given lake. The overall system is called LAKELOC. A detailed description of the hardware, program operations, water-detection algorithm, and associated outputs follows.

Hardware--The host computer is currently an IBM 360/65. The display controller used is a Ramtek G100B, a versatile video-display device that can

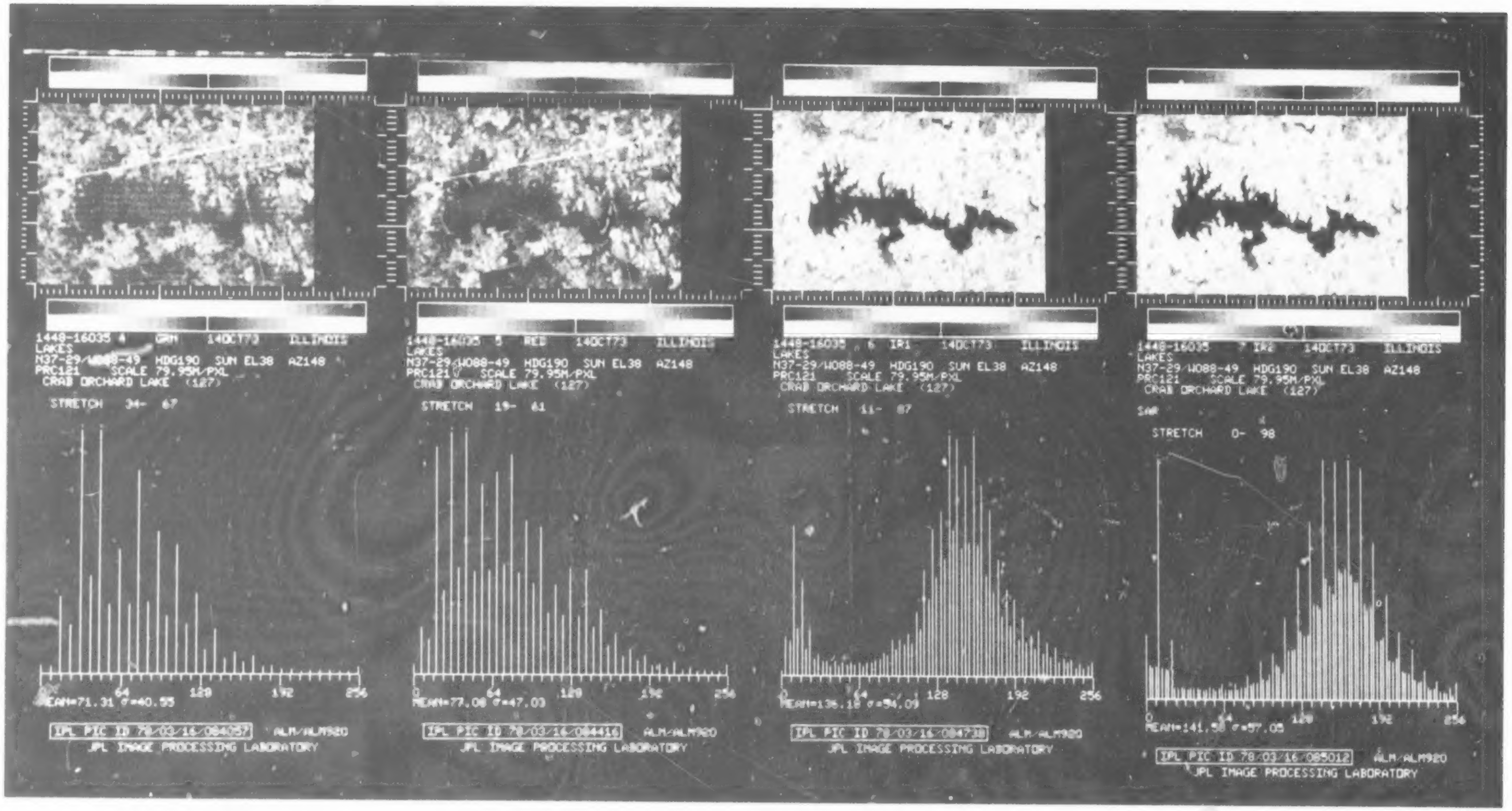

1448-16035 4 GRN 14OCT73 ILLINOIS
LAKES
N37-29/W088-49 HDG190 SUN EL38 AZ148
PRC121 SCALE 79.95M/PXL
CRAB ORCHARD LAKE (127)
STRETCH 34- 67
64
128
192
256
MEAN=71.31 σ=40.55
IPL PIC ID 78/03/16/084057 ALM/ALM920
JPL IMAGE PROCESSING LABORATORY
1448-16035 5 RED 14OCT73 ILLINOIS
LAKES
N37-29/W088-49 HDG190 SUN EL38 AZ148
PRC121 SCALE 79.95M/PXL
CRAB ORCHARD LAKE (127)
STRETCH 19- 61
0
64
128
192
256
MEAN=77.08 σ=47.03
IPL PIC ID 78/03/16/084416 ALM/ALM920
JPL IMAGE PROCESSING LABORATORY
1448-16035 6 IR1 14OCT73 ILLINOIS
LAKES
N37-29/W088-49 HDG190 SUN EL38 AZ148
PRC121 SCALE 79.95M/PXL
CRAB ORCHARD LAKE (127)
STRETCH 11- 87
0
64
128
192
256
MEAN=136.18 σ=54.09
IPL PIC ID 78/03/16/084738 ALM/ALM920
JPL IMAGE PROCESSING LABORATORY
1448-16035 7 IR2 14OCT73 ILLINOIS
LAKES
N37-29/W088-49 HDG190 SUN EL38 AZ148
PRC121 SCALE 79.95M/PXL
CRAB ORCHARD LAKE (127)
SAR
STRETCH 0- 98
0
64
128
192
256
MEAN=141.58 σ=57.05
IPL PIC ID 78/03/16/085012 ALM/ALM920
JPL IMAGE PROCESSING LABORATORY

Figure 32. GRN RED, IR1, and IR2 images of a LANDSAT scene 1448-16035 subscene. The histograms depict the DN distributions for the subscene including both the water bodies and the land cover. The large body is Crab Orchard Lake (serial number 127) in Williamson County.

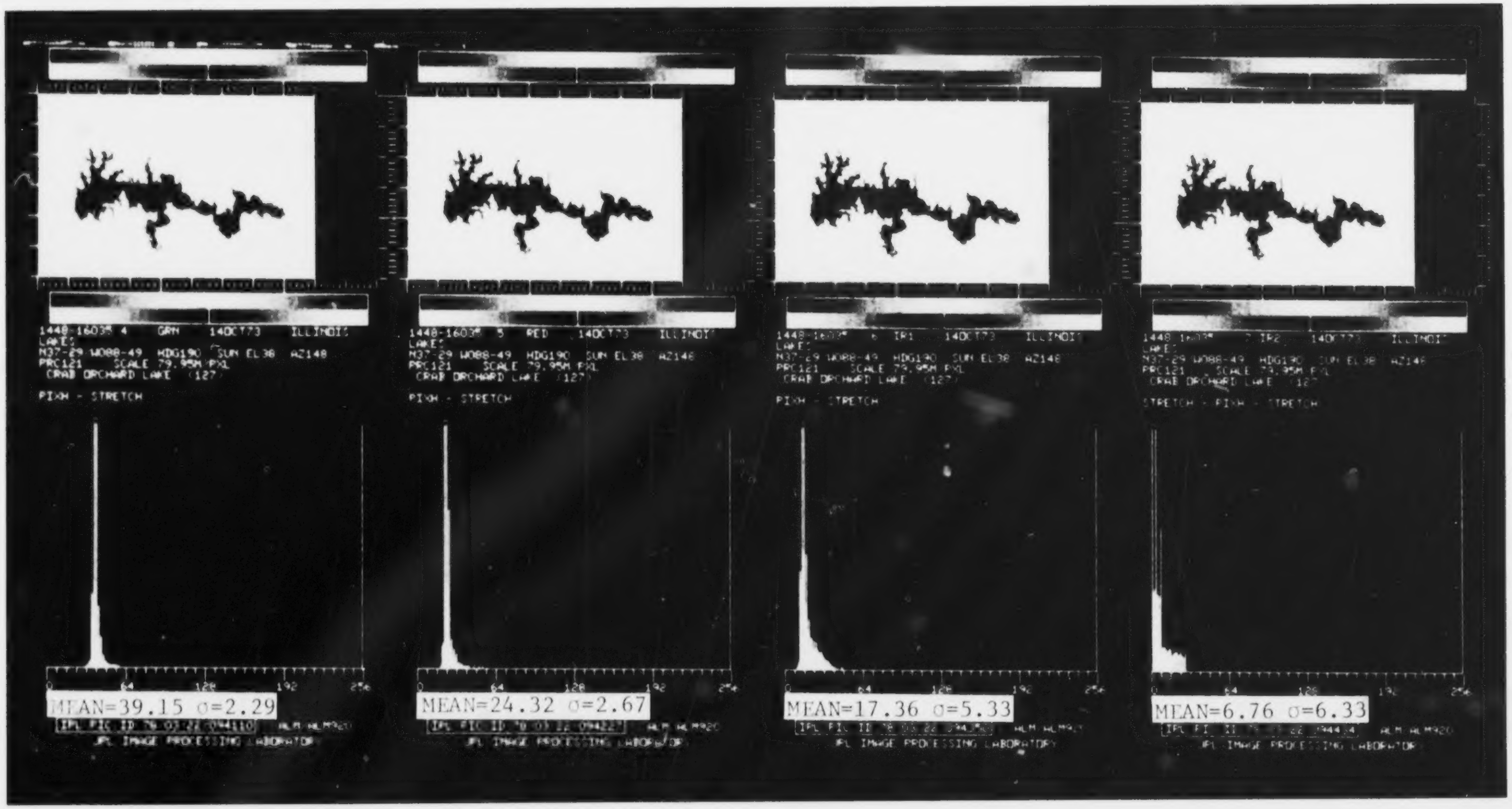


Figure 33. GRN, RED, IR1, and IR2 images of a LANDSAT scene 1448-16035 subscene after the application of the binary mask. The histograms depict the DN distributions for Crab Orchard Lake (serial number 127).

be used to display grey-level images and graphics data. The Ramtek is a solid-state refresh memory system with a display format of 512 lines by 640 elements. Readback from the refresh memory is available under software control. It is possible to display six-bit gray-level images along with two graphics planes, and the user may selectively write or erase the displays point by point. Manipulation of the graphics data can be accomplished with the aid of a trackball cursor. Figure 34 illustrates the configuration of the interactive hardware as it is arranged for the operation of the LAKELOC program.

Operation of LAKELOC--For the purposes of illustration, the operation of LAKELOC as it would be applied to a scene in southern Illinois is described below. Although any number of lakes could be extracted from a scene, this description will be limited to one lake, in this case Crab Orchard Lake, located in scene 1448-16035.

For a given digital data scene, such as LANDSAT, the user may selectively display 512-by-640 element subsections until he locates the water body of interest. Automatic linear contrast stretching of the displayed scene can be performed during this operation to aid in the location of the lake.

Once a lake has been located, the trackball cursor is set on the desired lake and a default 50-by-50 element box is drawn on the graphics plane about the cursor position. Figure 35 illustrates the default box drawn about the cursor positioned on Crab Orchard Lake. Since only the area within the box will be acted on by the water detector, the user must correct the size and the position of the box relative to the lake so that the lake is contained within the box boundaries. The size is changed by a simple command to the program that allows the manipulation of the trackball cursor to control the box dimensions. The position of the box is also controlled in the same manner by the trackball. Figure 36 illustrates Crab Orchard Lake completely enclosed by the box after manipulation of the cursor.

Once the box has been satisfactorily positioned about the lake boundaries, the user is able to invoke the water detector to isolate the water body in a binary form. A detailed description of the water detector follows in the subsection entitled Water Detection Algorithm. In the binary form, the water bodies appear as white, and nonwater features as black. At this time the user can magnify the area within the box boundaries by issuing a "zoom" command with the appropriate magnification factor. The zoom command redisplays a magnified picture of the boxed area directly over the existing image. At the conclusion of the edit session, the magnified image is erased from the screen leaving the original image. This allows the user to continue uninterrupted with other lakes contained in the existing scene.

Magnification of the image allows the user to easily determine the exact boundaries of the lake as opposed to any extraneous water information that may also be displayed in the scene. Figure 37 illustrates Crab Orchard Lake. The detached white areas represent extraneous water information that is not associated with the lake. The task of editing out extraneous pixels has been in the past the most time-consuming chore in the water analysis project. Aided only infrequently by a map, the user must decide what constitutes the

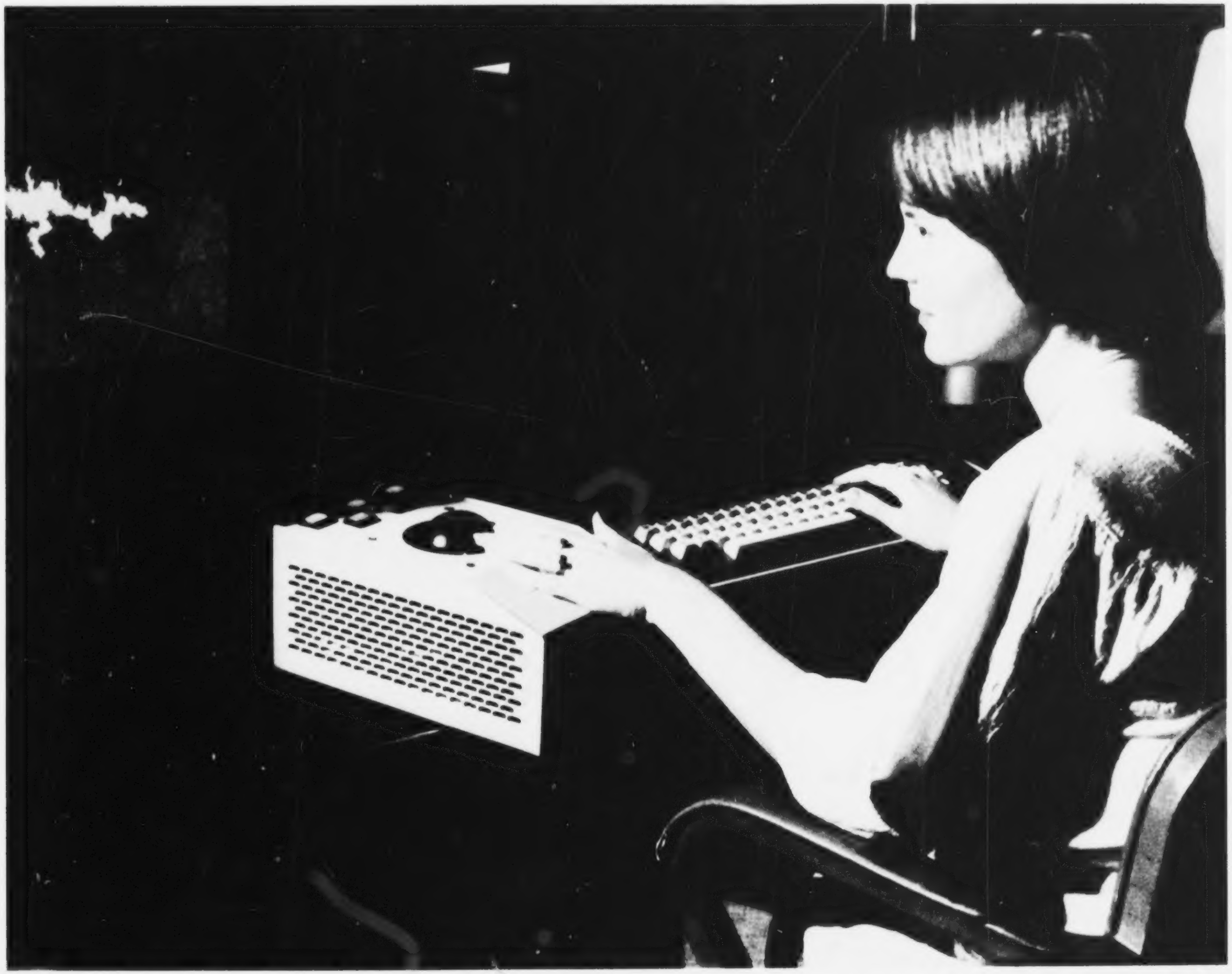


Figure 34. Interactive user console with video-display device and trackball. The system is located in the Jet Propulsion Laboratory's Image Processing Laboratory, Pasadena, California.

boundaries of the lake in question. Previously, the user relied on pixel listings and hard-copy photographs to locate the lake boundaries. In the case of a large lake, one was often hampered by cumbersome pixel listings that had to be carefully pieced together to re-create a lake image. With LAKELOC, the magnification factor, used in conjunction with the easily manipulated trackball, allows the user to perform the editing task in a matter of minutes as opposed to a duration of several days.

The removal of water bodies not associated with the lake of interest can be performed in two ways. In the first method the trackball controlled cursor is set point by point on the areas to be removed. The default size of the area removed is one pixel; however, the user can specify the number of surrounding pixels to be removed for each erase operation. This method is most useful when working in close proximity to the boundaries of the lake of interest, where it is imperative not to remove too large a section of pixels close to the lake. The second method utilizes continuous erasures as the trackball cursor is moved across the screen. The size of the area about the cursor position to be erased can also be controlled by the user in this mode. Figure 38 depicts Crab Orchard Lake after all extraneous information has been removed during the editing phase.

Once the user is satisfied that he has isolated the lake of interest, he assigns the lake a name and commands the program to save the binary image of the lake on a disk data set. The lake's position in the disk data set is exactly the same as it is in the original LANDSAT scene. LAKELOC returns to the user the exact position and size of the extracted lake image as it appears on the disk data set; a parameter data set that contains this positional information is also created. This information is necessary to the operation of the follow-on programs for LAKELOC. At this time the user is able to continue processing any number of lakes or, if finished, to fetch the follow-on programs that will process the statistical data.

Follow-on programs--The output from LAKELOC consists of a binary mask disk data set containing the extracted lakes and a parameter data set containing the positional information and lake names. The output size of the binary disk data set is exactly the same as the size of the original LANDSAT image used as input to LAKELOC. In the next step, the binary data set is used by the program FARINA to mask out of each corresponding spectral channel in the original LANDSAT frame the water features that have been processed through LAKELOC. The output is four data sets containing the original DN values for each lake in each of the spectral bands. This output can in turn be used as input to the program STATUS and as input to follow-on MSS classification programs.

STATUS, utilizing the parameter data set from LAKELOC or punched parameter cards, produces a statistical analysis in the form of a hard-copy listing of lake statistics in all four spectral channels. The lakes are listed by name and ranked according to size. Two tables are printed. The first (Table 5) consists of lake statistics such as pixel count, surface area calculations, and shoreline perimeter calculations. The second, Table 6, lists lake MSS statistics, such as the mean DN level for each lake in each spectral channel, and the corresponding standard deviations.

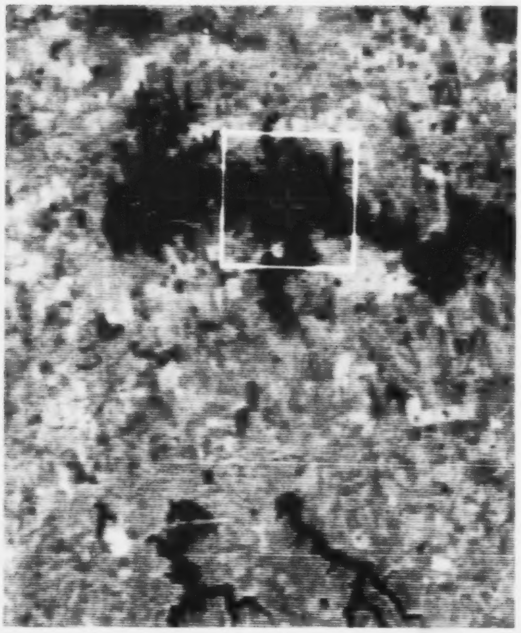


Figure 35. Crab Orchard Lake with default 50-by-50 element box. This is a subsection of scene 1448-16035 (October 14, 1973).

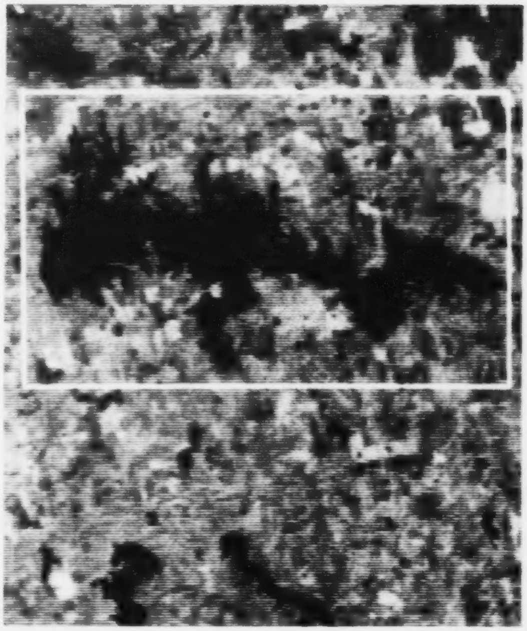


Figure 36. Crab Orchard Lake contained within correctly positioned box.

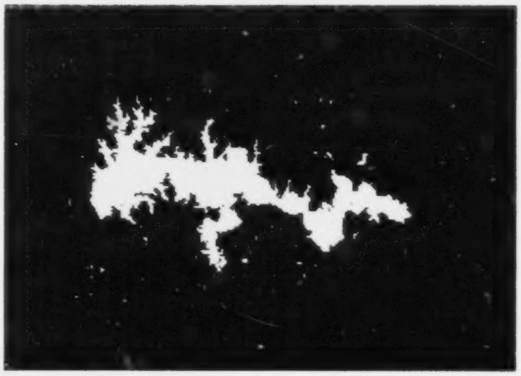


Figure 37. Crab Orchard Lake in binary form (with magnification factor of 2) before editing of extraneous water information.

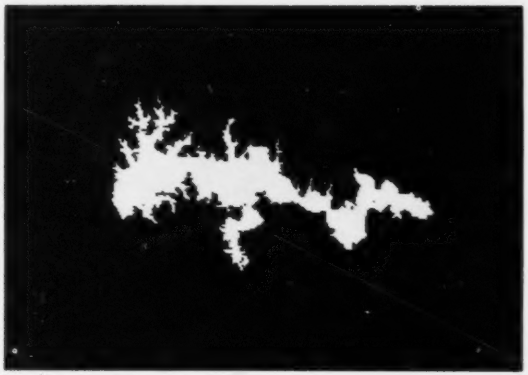


Figure 38. Crab Orchard Lake in final, edited form.

TABLE 5. AREAL STATISTICS FOR EXAMPLE LAKES*

*** LAKE STATISTICS ***

** LAKE NAME **	** TOTAL PIXELS **	** SURFACE AREA **			** SHORELINE **	
		SQUARE FEET	ACRES	HECTARES	FEET	METERS
Pinckneyville 99	59	4064451.0	93.3	37.8	11650.1	3550.8
DuQuoin 98	74	5097786.0	117.0	47.4	17379.6	5297.0
Washington Co 123	103	7095567.0	162.9	65.9	31260.7	9527.8
Devil's Kitchen 128	338	23284432.0	534.5	216.3	84010.2	25605.1
Little Grassy 119	547	37682283.0	865.1	350.1	101302.8	39875.6
Cedar 39	855	58900095.0	1352.2	547.2	161456.4	49209.5
Egypt 132	1121	77224569.0	1772.8	717.4	240158.9	73196.9
Kinkaid 40	1267	87282363.0	2003.7	810.9	239724.2	73064.4
Crab Orchard 127	4027	277416003.0	6368.6	2577.3	363440.0	110771.1
Rend 29	10694	736698966.0	16912.2	6844.1	583720.1	177909.3

*Computer-generated table.

TABLE 6. MSS DN STATISTICS FOR EXAMPLE LAKES*

*** LAKE MSS STATISTICS ***

** LAKE NAME **	** MEAN **				*	** STANDARD DEVIATION **			
	GREEN	RED	IR1	IR2	*	GREEN	RED	IR1	IR2
Pinckneyville 99	45.03	28.71	23.71	11.36	*	2.75	2.23	5.86	6.65
DuQuoin 98	35.04	18.28	19.22	9.88	*	2.33	2.03	5.92	6.44
Washington Co 123	40.63	27.75	25.39	13.42	*	5.93	8.53	8.98	7.81
Devil's Kitchen 128	33.12	16.12	17.38	9.89	*	1.78	1.86	6.80	7.89
Little Grassy 119	36.83	18.60	16.98	9.08	*	2.54	2.52	6.74	7.86
Cedar 39	34.68	19.15	17.80	9.16	*	2.51	3.00	6.38	7.54
Egypt 132	38.27	22.81	20.06	10.92	*	3.68	3.50	7.83	9.10
Kinkaid 40	35.89	18.94	17.58	9.68	*	3.00	3.65	7.30	7.77
Crab Orchard 127	38.84	23.69	20.82	8.13	*	3.11	3.47	6.37	6.40
Rend 29	40.50	26.73	19.87	7.03	*	5.46	6.51	7.49	6.11

*Computer-generated table.

Water detection algorithm -- In the past, the detection of pixels whose instantaneous field of view (IFOV) is that of water was done in the straightforward manner of thresholding band 7 (IR2) as described previously. The low reflectance of water in this spectral range conveniently produced a bimodal distribution of DN's -- one peak for water, another peak for nonwater. This technique works quite well except in the case where the IFOV of the scanner is viewing a combination of water and nonwater areas such as the shoreline of a lake or where cloud shadows straddle the water-land interface. In this situation, the problem becomes one of trying to estimate the proportion of each material in the IFOV.

Horowitz et al. (1971) and Work and Gilmer (1976) have investigated the proportion-estimation problem with encouraging results. Work and Gilmer have estimated the proportions of water, bare soils, and green vegetation using LANDSAT bands 5 and 7. This technique requires an estimate of the spectral signature for pure water, pure bare soil, and pure vegetation. While the spectral signature of water is fairly easy to estimate, that for soil and vegetation becomes more difficult. The many variables involved, such as different soil types, vegetative cover types, and thickness of the vegetative cover, cause considerable error when estimation is attempted by a completely automatic processor.

An alternate approach, and the one chosen for implementation, considers the mixture classes to be only water and nonwater. Bands 5 (RED) and 7 (IR2) are used in the detection process; bands 4 (GRN) and 6 (IR1) offer little additional information. The estimation of the spectral signature for water and nonwater is made over a region within, and immediately surrounding, the water body.

The spectral signatures (mean DN values) are estimated by an iterative procedure. First, the two-dimensional space (band 5 vs. band 7) is partitioned into two regions in which the populations of water and nonwater typically cluster. The mean is then recomputed for those DN's that fall within a neighborhood of the initial mean. This process is continued until a convergent mean has been found for each region.

The proportion estimation that was implemented uses a technique proposed by McCloy (1977). In Figure 39, W is the mean for water, U is the mean for nonwater, and P is the DN for any given pixel. P' is the projection of P onto the line segment WU. If /WU/ is the length of the line segment WU, and /WP'/ is the length of line segment WP', then the proportion estimate q for water is:

$$q = 1 - \frac{/WP'/}{/WU/}$$

where

$$0 \leq q \leq 1$$

If P' does not fall between W and U, it is given the position of the closest point, W or U. A decision threshold is set for q at which the pixel is defined to be water or nonwater.

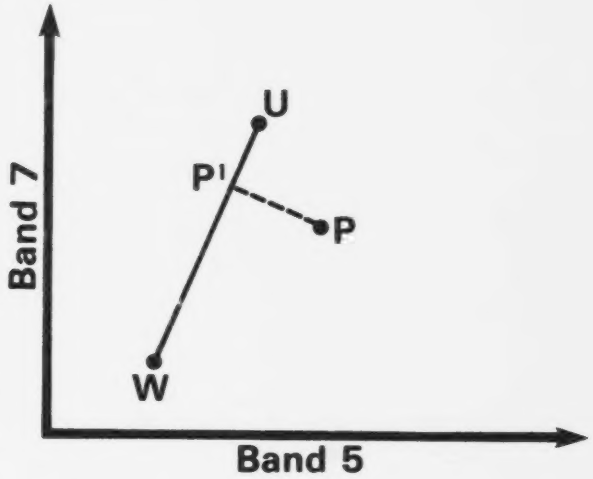


Figure 39. Geometric interpretation of the water-detection algorithm.

Both the batch and interactive modes of lake extraction provide the user with MSS data related to the specific water bodies under consideration. For this project, the band averages for each lake were used, a consequence of several factors including time and cost.

Average spectral responses for each band for all pixels in a lake do not account for the variability of responses for a specific portion of a lake and its associated optical properties. Thus, lake characterization using average spectral responses for each band demonstrates the average lake response and not the variation actually measured. An examination of LANDSAT DN-level histograms for all study lakes supports the idea that lakes, as viewed by the MSS, are heterogeneous bodies. For example, Figure 40 illustrates the nonhomogeneous nature of Cedar Lake (serial number 55). Although this aspect of lakes is recognized, data extraction and subsequent analyses largely utilized a "whole lake" concept by using band values averaged over all the lake pixels. This technique provides a general spectral response for a given lake but does not differentiate between extreme readings within a wavelength band, nor does it demonstrate precise variations in spectral composition.

The data for each of the project lakes in a LANDSAT scene were treated in this manner. After final editing, the IR2 images of lakes from a particular scene were concatenated into one or two photographs (Figures 41-48). In general, side overlap water bodies, those found in LANDSAT scenes of two consecutive dates (e.g., October 14 and 15), appear in only one concatenation. Forward overlap water bodies, those found in the 10 percent forward overlap area of two scenes of the same date (e.g., Sawmill Lake (serial number 103) in scenes 1449-16082 and 1449-16084), were only extracted from one scene and appear in only one concatenation.

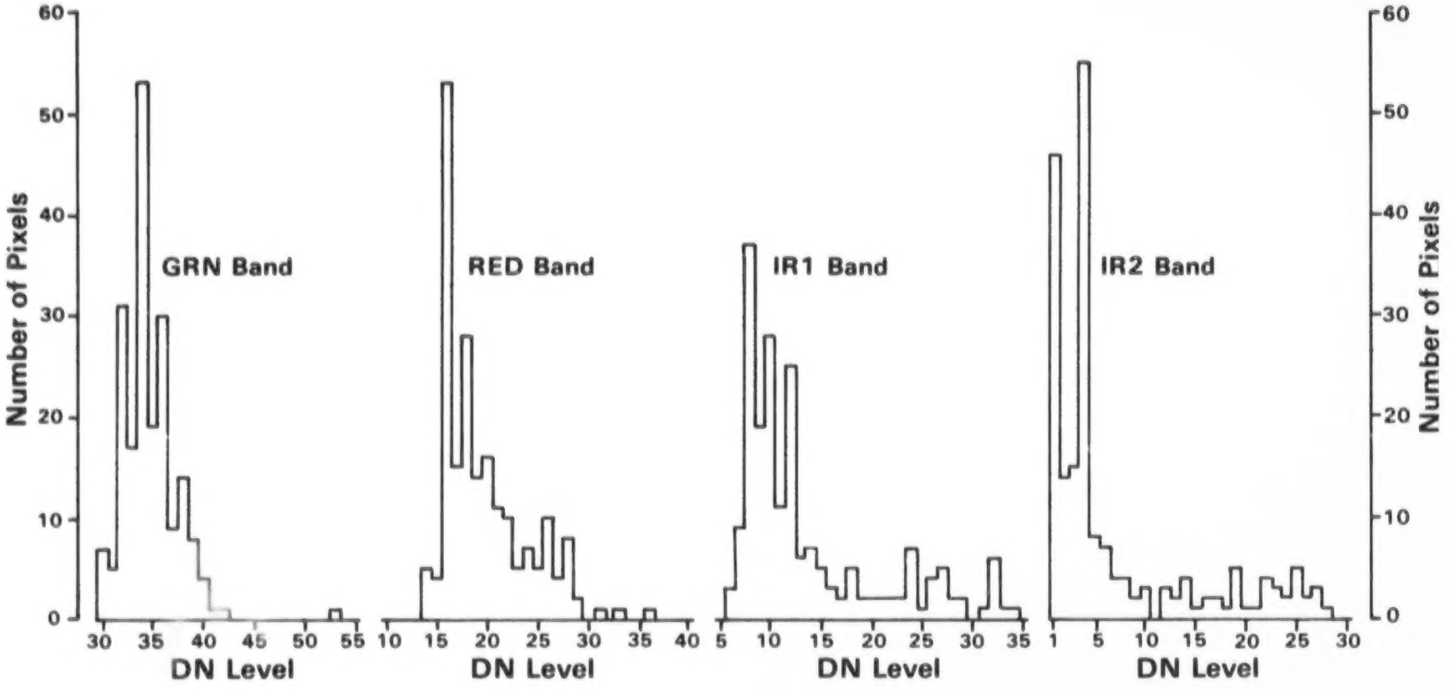
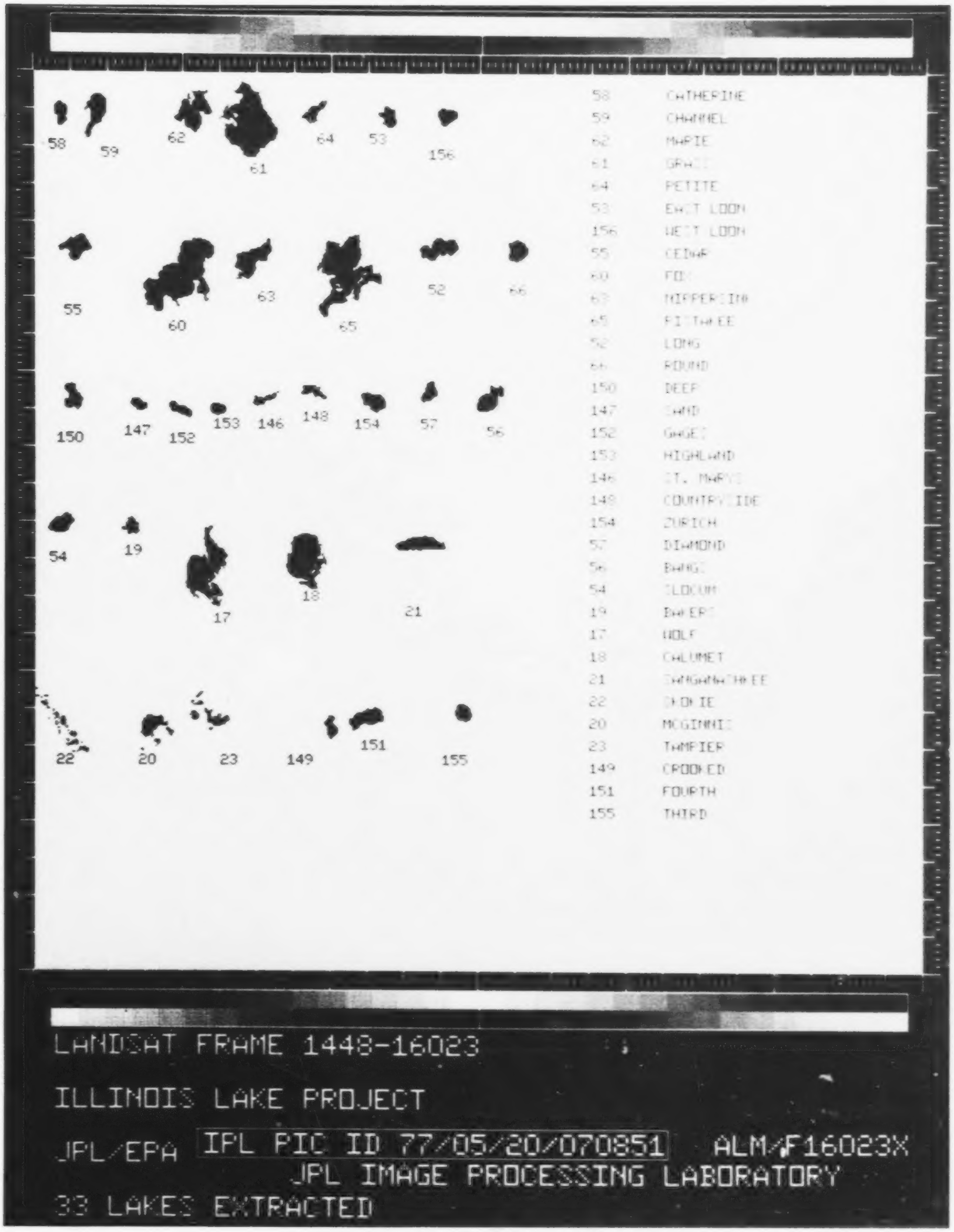


Figure 40. LANDSAT MSS histograms of four bands of Cedar Lake (serial number 55). The data were extracted from scene 1448-16023.


58
59
62
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156
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65
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150
147
152
153
146
148
154
57
56
54
19
17
18
21
22
20
23
149
151
155

58	CATHERINE
59	CHANNEL
62	MARIE
61	GRASS
64	PETITE
53	EAST LOON
156	WEST LOON
55	CEDAR
60	FOX
63	NIPPERSINK
65	PISTAKEE
52	LONG
66	ROUND
150	DEEP
147	SAND
152	GAGES
153	HIGHLAND
146	ST. MARYS
148	COUNTRYSIDE
154	ZURICH
57	DIAMOND
56	BANGS
54	SLOCUM
19	BAKERS
17	WOLF
18	CALUMET
21	SANGANASHKEE
22	SKOKIE
20	MCGINNIS
23	TAMPIER
149	CROOKED
151	FOURTH
155	THIRD

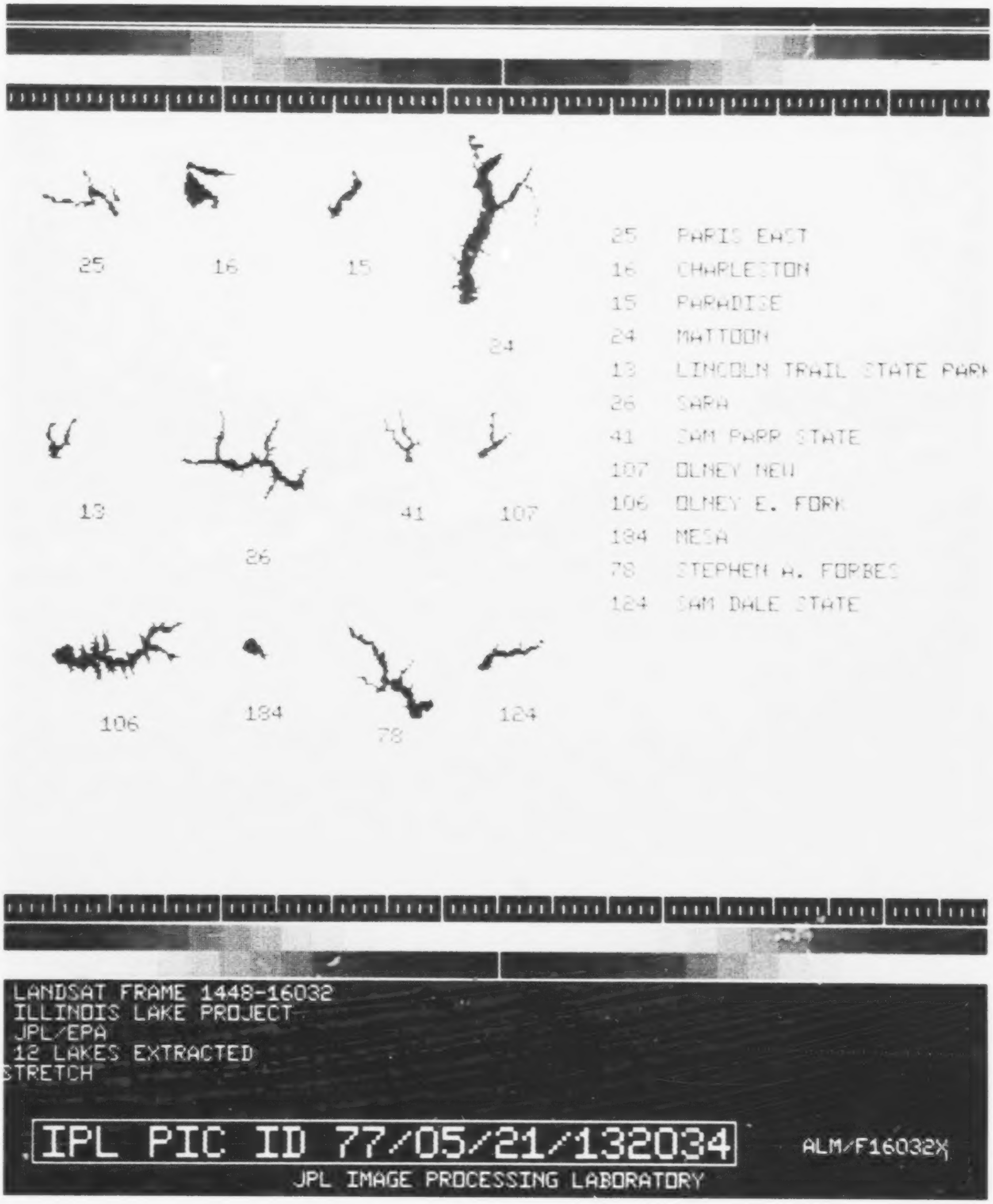
LANDSAT FRAME 1448-16023

ILLINOIS LAKE PROJECT

JPL/EPA IPL PIC ID 77/05/20/070851 ALM/F16023X
JPL IMAGE PROCESSING LABORATORY

33 LAKES EXTRACTED

Figure 41. IR2 concatenation of 33 Illinois water bodies extracted from LANDSAT scene 1448-16023 (October 14, 1973).



25	PARIS EAST
16	CHARLESTON
15	PARADISE
24	MATTOON
13	LINCOLN TRAIL STATE PARK
26	SARA
41	SAM PARR STATE
107	OLNEY NEW
106	OLNEY E. FORK
184	MESA
78	STEPHEN A. FORBES
124	SAM DALE STATE

LANDSAT FRAME 1448-16032
ILLINOIS LAKE PROJECT
JPL/EPA
12 LAKES EXTRACTED
STRETCH

IPL PIC ID 77/05/21/132034
ALM/F16032X
JPL IMAGE PROCESSING LABORATORY

Figure 42. IR2 concatenation of 12 Illinois water bodies extracted from LANDSAT scene 1448-16032 (October 14, 1973). See Figure 18 for 20 more lakes extracted from the scene.

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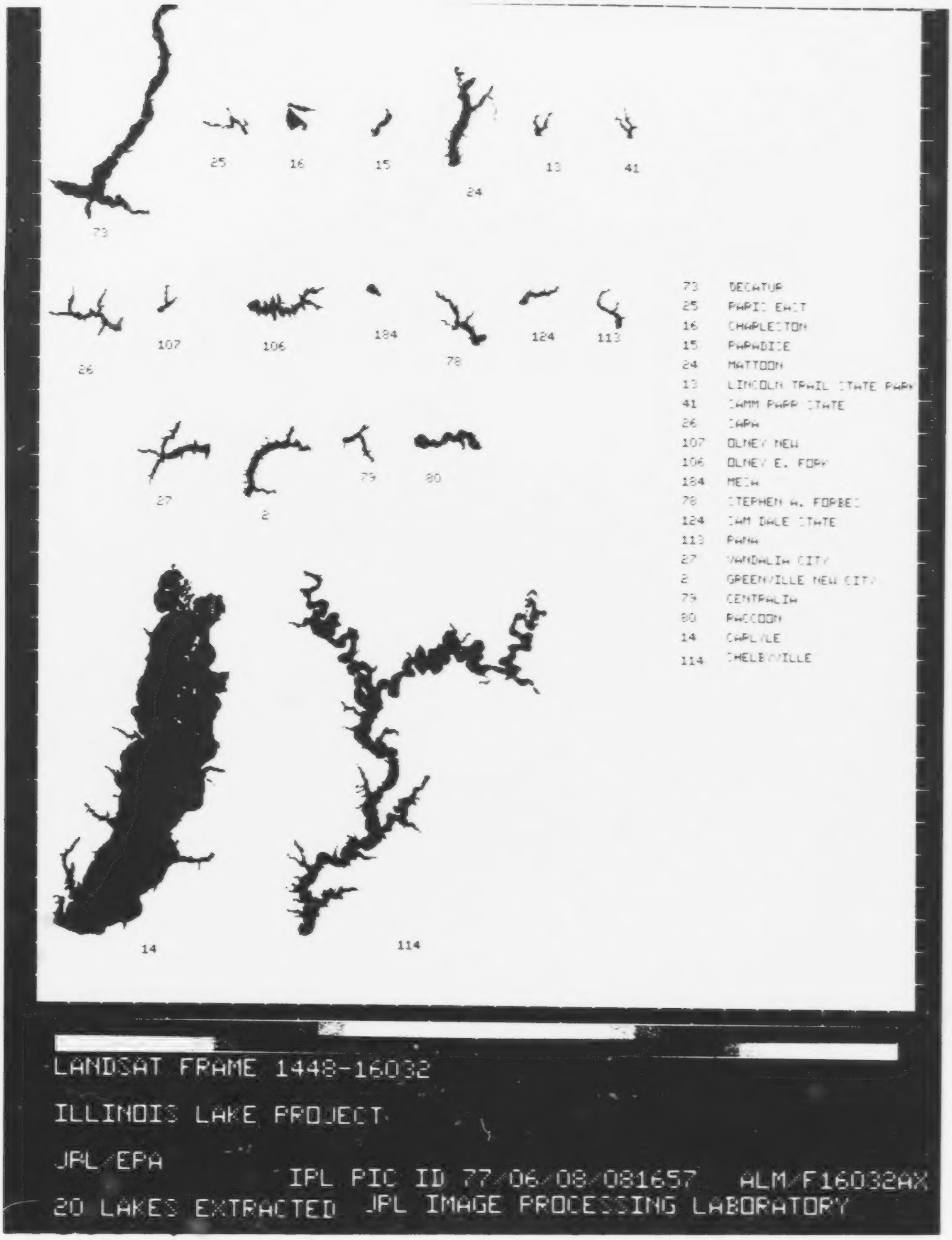
25
16
15
24
13
41
73
26
107
106
184
78
124
113
27
2
79
80
14
114
73 DECATUR
25 PARIS EAST
16 CHARLESTON
15 PARADISE
24 MATTOON
13 LINCOLN TRAIL STATE PARK
41 SAMM PARR STATE
26 SARA
107 OLNEY NEW
106 OLNEY E. FORK
184 MESA
78 STEPHEN A. FORBES
124 SAM DALE STATE
113 PANA
27 VANDALIA CITY
2 GREENVILLE NEW CITY
79 CENTRALIA
80 RACCOON
14 CARLYLE
114 SHELBYVILLE
LANDSAT FRAME 1448-16032
ILLINOIS LAKE PROJECT
JPL/EPA
IPL PIC ID 77/06/08/081657 ALM/F16032AX
20 LAKES EXTRACTED JPL IMAGE PROCESSING LABORATORY

Figure 43. IR2 concatenation of 20 Illinois water bodies extracted from LANDSAT scene 1448-16032 (October 14, 1973). See Figure 17.

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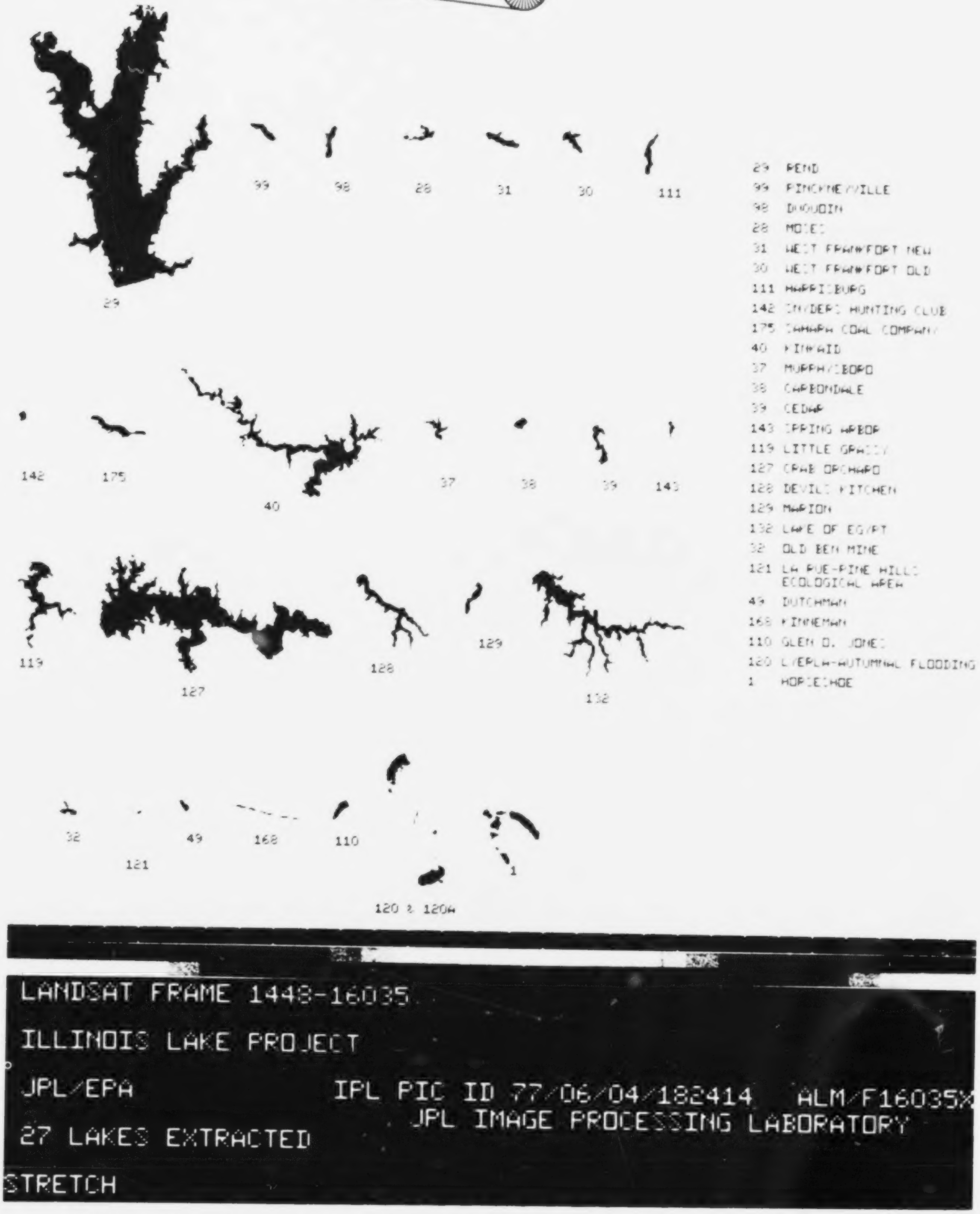
29
99
98
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31
30
111
142
175
40
37
38
39
143
119
127
128
129
132
32
121
49
168
110
120 & 120A
1
29 REND
99 PINCKNEYVILLE
98 DUQUOIN
28 MOSES
31 WEST FRANKFORT NEW
30 WEST FRANKFORT OLD
111 HARRISBURG
142 SNYDERS HUNTING CLUB
175 SAHARA COAL COMPANY
40 KINKAID
37 MURPHYSBORO
38 CARBONDALE
39 CEDAR
143 SPRING ARBOR
119 LITTLE GRASSY
127 CRAB ORCHARD
128 DEVILS KITCHEN
129 MARION
132 LAKE OF EGYPT
32 OLD BEN MINE
121 LA RUE-PINE HILLS ECOLOGICAL AREA
49 DUTCHMAN
168 KINNEMAN
110 GLEN O. JONES
120 LYERLA-AUTUMNAL FLOODING
1 HORSESHOE
LANDSAT FRAME 1448-16035
ILLINOIS LAKE PROJECT
JPL/EPA
IPL PIC ID 77/06/04/182414
ALM/F16035X
JPL IMAGE PROCESSING LABORATORY
27 LAKES EXTRACTED
STRETCH

Figure 44. IR2 concatenation of 27 Illinois water bodies extracted from LANDSAT scene 1448-16035 (October 14, 1973).

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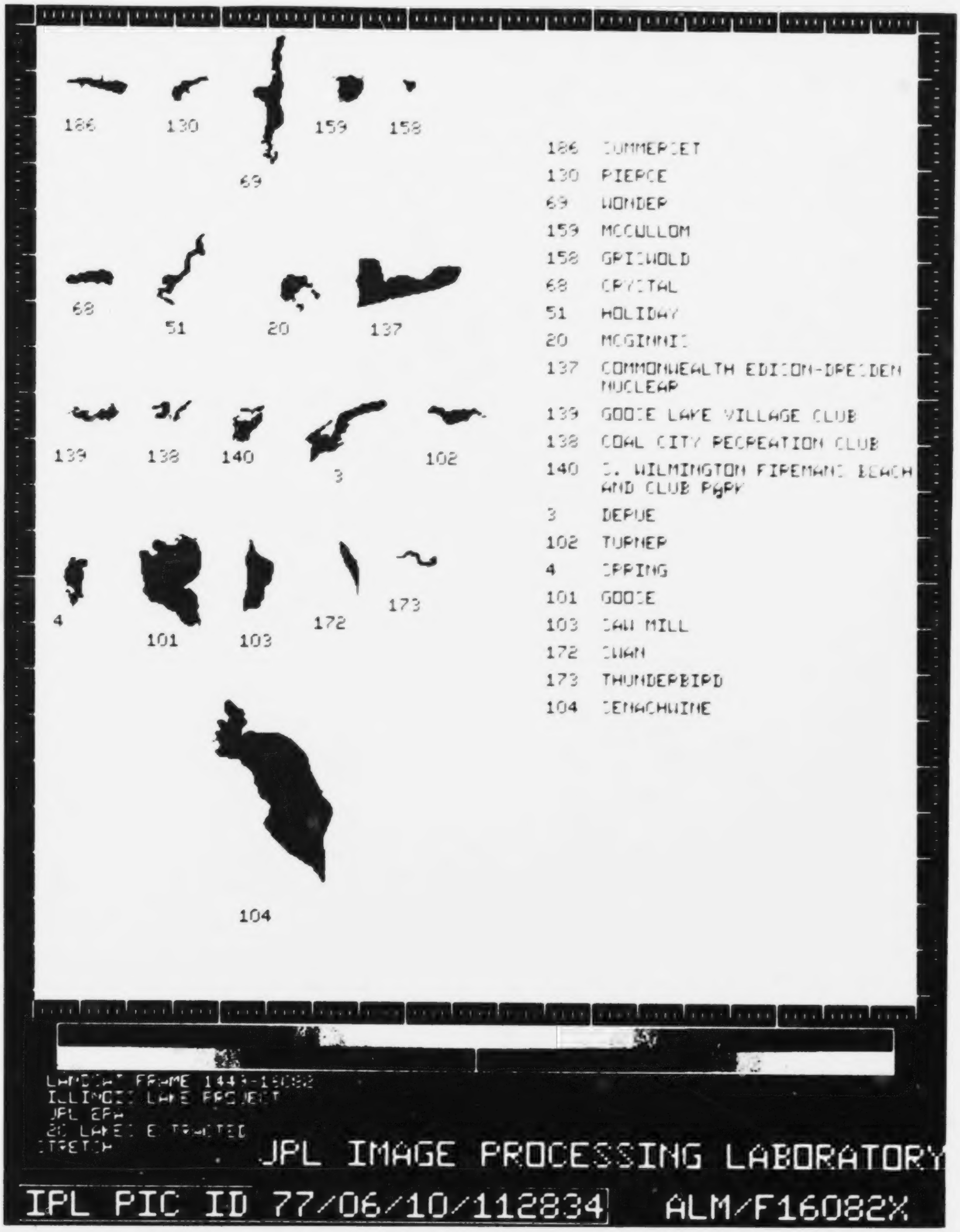

186	SUMMERSET
130	PIERCE
69	WONDER
159	MCCULLOM
158	GRISWOLD
68	CRYSTAL
51	HOLIDAY
20	MCGINNIS
137	COMMONWEALTH EDISON-DRESDEN NUCLEAR
139	GOOSE LAKE VILLAGE CLUB
138	COAL CITY RECREATION CLUB
140	S. WILMINGTON FIREMANS BEACH AND CLUB PARK
3	DEPUE
102	TURNER
4	SPRING
101	GOOSE
103	SAW MILL
172	SWAN
173	THUNDERBIRD
104	SENACHWINE

LANDSAT FRAME 1449-16082
ILLINOIS LAKE PROJECT
JPL EPA
20 LAKES EXTRACTED
STRETCH

JPL IMAGE PROCESSING LABORATORY

IPL PIC ID 77/06/10/112834 ALM/F16082X

Figure 45. IR2 concatenation of 20 Illinois water bodies extracted from LANDSAT scene 1449-16082 (October 15, 1973).

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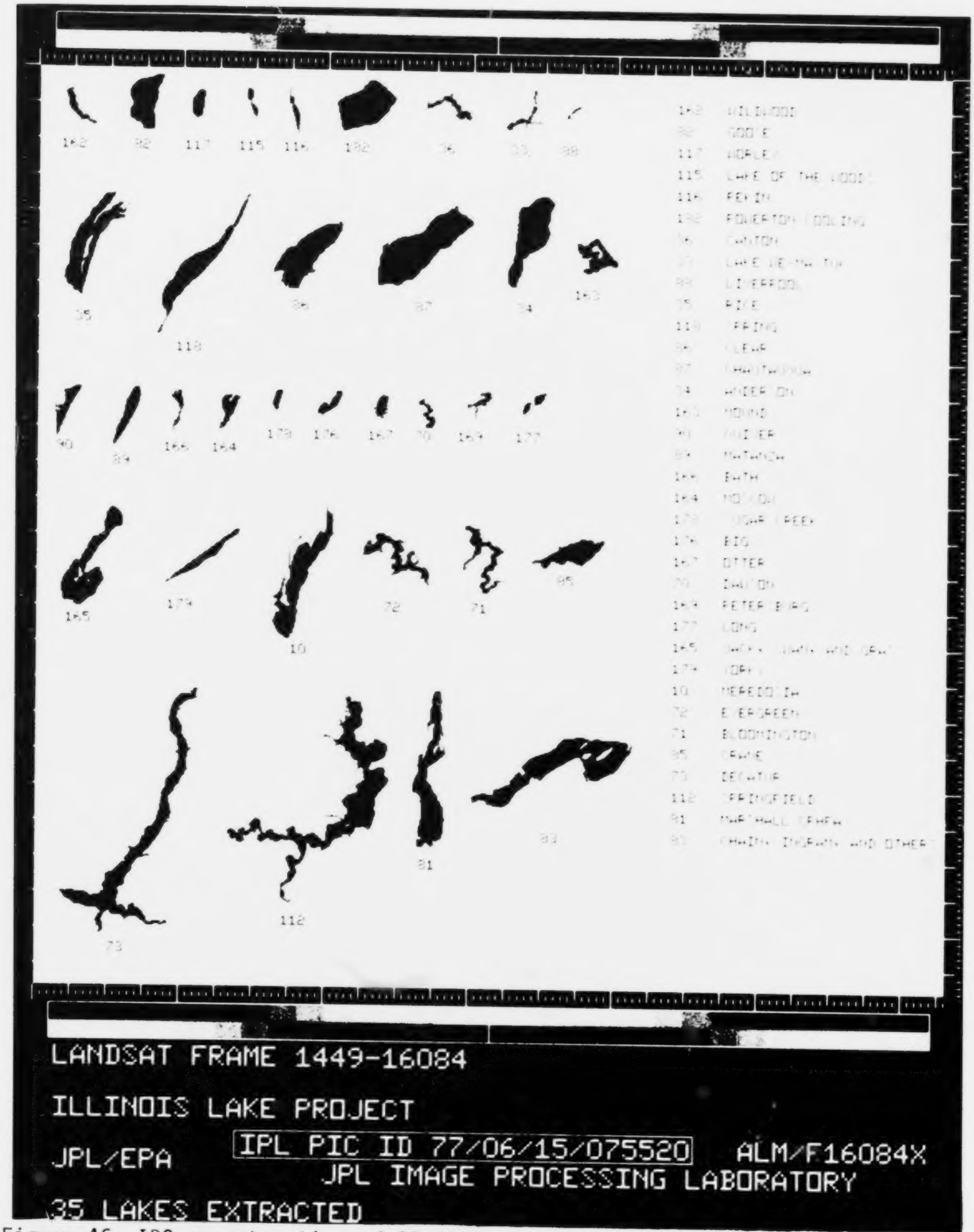
162
82
117
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116
182
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178
176
167
70
169
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165
179
10
72
71
85
73
112
81
83
162 WILDWOOD
82 GOODE
115 LAKE OF THE WOODS
116 PEKIN
182 POWERTON COOLING
36 CANTON
88 LIVERPOOL
35 RICE
118 SPRING
86 CLEAR
87 CHAUTAUQUA
34 ANDERSON
163 MOUND
89 MATANZA
166 BATH
178 SUGAR CREEK
176 BIG
167 OTTER
70 DAWSON
169 PETERSBURG
177 LONG
10 MEREDOSIA
72 EVERGREEN
71 BLOOMINGTON
85 CRANE
73 DECATUR
112 SPRINGFIELD
83 CHAIN, INGRAM AND OTHER
LANDSAT FRAME 1449-16084
ILLINOIS LAKE PROJECT
JPL/EPA
IPL PIC ID 77/06/15/075520
ALM/F16084X
JPL IMAGE PROCESSING LABORATORY
35 LAKES EXTRACTED

Figure 46. IR2 concatenation of 35 Illinois water bodies extracted from LANDSAT scene 1449-16084 (October 15, 1973). The CCT's for this scene were supplied without the necessary internal calibration data.

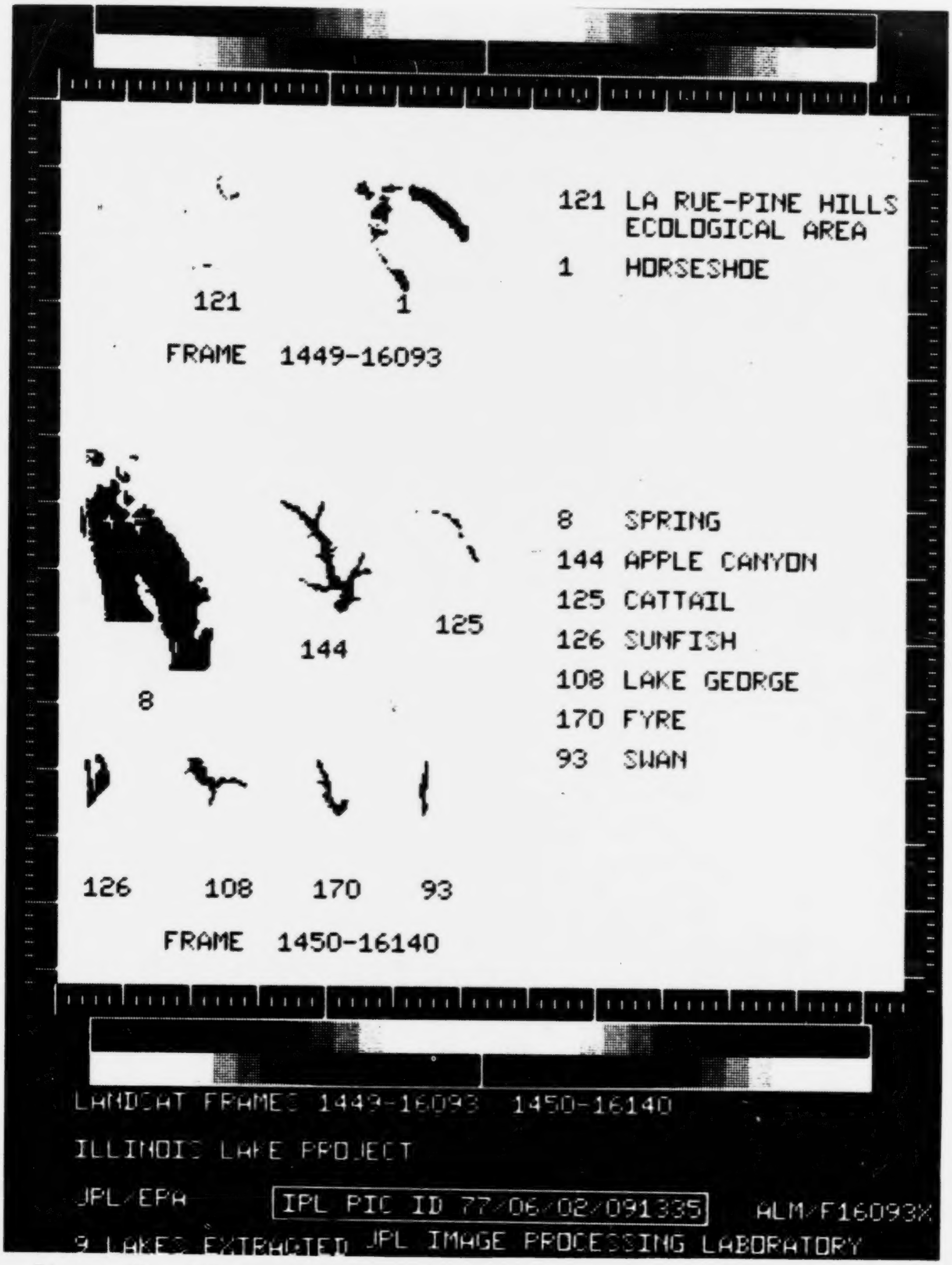
121 LA RUE-PINE HILLS ECOLOGICAL AREA
1 HORSESHOE
121
1
FRAME 1449-16093
8 SPRING
144 APPLE CANYON
125 CATTAIL
126 SUNFISH
108 LAKE GEORGE
170 FYRE
93 SWAN
8
144
125
126
108
170
93
FRAME 1450-16140
LANDSAT FRAMES 1449-16093 1450-16140
ILLINOIS LAKE PROJECT
JPL/EPA
IPL PIC ID 77/06/02/091335
ALM/F16093X
9 LAKES EXTRACTED
JPL IMAGE PROCESSING LABORATORY

Figure 47. IR2 concatenation of nine Illinois water bodies extracted from LANDSAT scenes 1449-16093 (October 15, 1973) and 1450-16140 (October 16, 1973).

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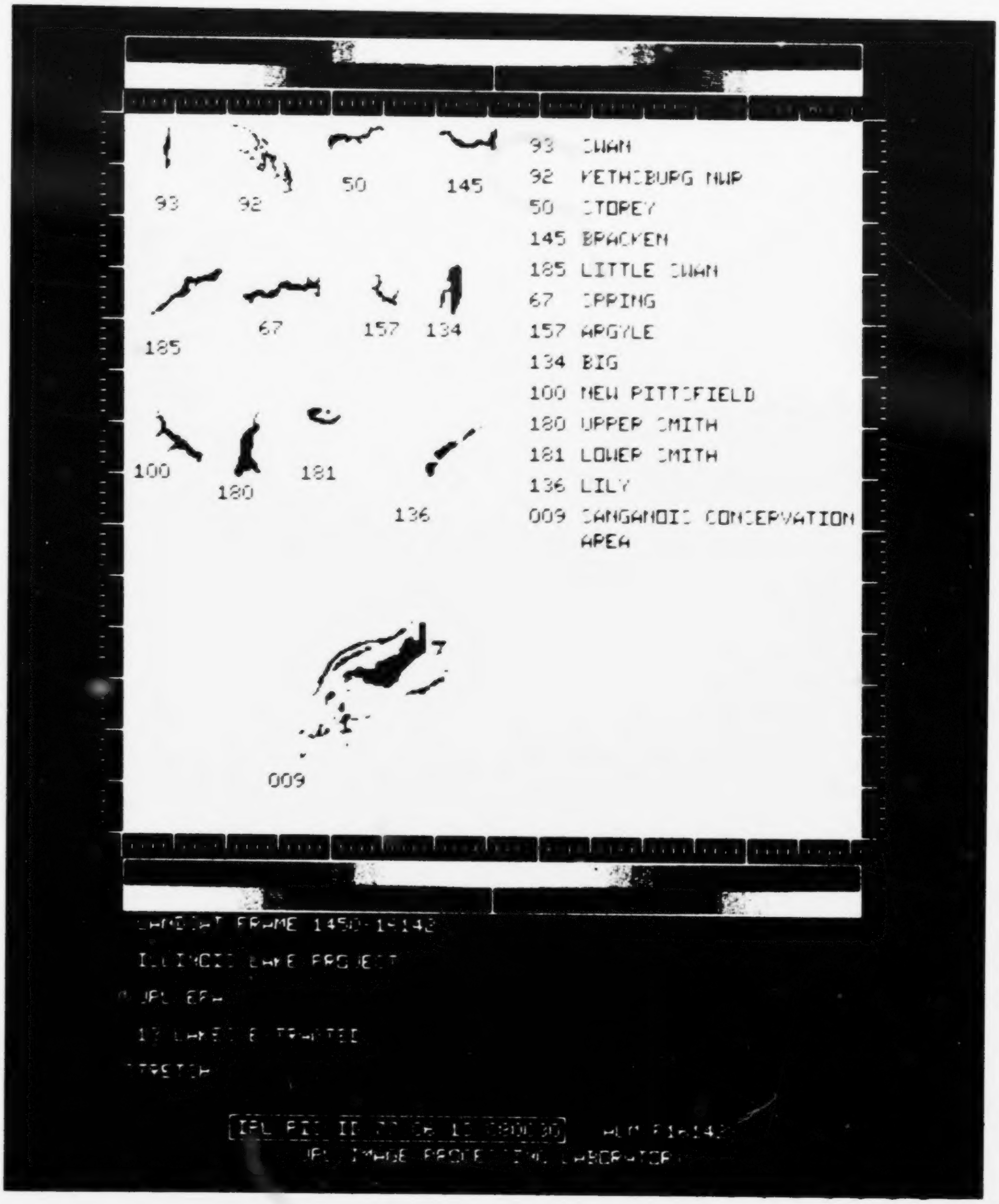

93
92
50
145
185
67
157
134
100
180
181
136
009
93 SWAN
92 KETHSBURG NWR
50 STOREY
145 BRACKEN
185 LITTLE SWAN
67 SPRING
157 ARGYLE
134 BIG
100 NEW PITTSFIELD
180 UPPER SMITH
181 LOWER SMITH
136 LILY
009 SANGANOIS CONSERVATION AREA
LANDSAT FRAME 1450-16142
ILLINOIS LAKE PROJECT
JPL EPA
13 LAKES
STRETCH
IPL PIC ID
JPL IMAGE PROCESSING LABORATORY

Figure 48. IR2 concatenation of 13 Illinois water bodies extracted from LANDSAT scene 1450-16142 (October 16, 1973).

Multispectral Data Adjustment

Complete multispectral scanner data coverage for Illinois requires overlapping the data from three passes of the satellite, as shown earlier in Figure 19. Thus, the raw data set consists of three subsets that are defined by the orbit during which the information was gathered. This stratification in the raw data set required that certain transformations be effected to create a single, unified, date-independent base that could be used for further analyses.

To accomplish this restructuring, use is made of the fact that lakes on the eastern and western edges of the scenes (i.e., side overlap lakes) appear on successive passes. Thus, within the larger data set, there are two subsets -- the October 14 and 15 overlap and the October 15 and 16 overlap.

It appears reasonable, from an examination of the operation of the satellite, the multispectral scanner, and the resultant data, to expect that the raw data pairs for the side overlap lakes represent the sum of small random and systematic effects. If the effects are almost entirely random, they will be reflected in any statistical adjustments as increases in the errors of estimation. Although systematic effects can contribute both additively and multiplicatively, multiplicative effects should be minimized by calibration of the MSS. Thus, it appeared reasonable, both from consideration of the processes involved in generating the data and from plotting side overlap data pairs, that simple linear relationships could be established for each of the four bands and for each of the two pairs of dates.

The models that were developed are presented in Table 7. As expected, the slopes are close to 1.00, the relationship being better for the 14th to 15th conversion than for the 16th to 15th. This may be largely the result of the greater number of degrees of freedom available for the former estimates.

Data from scene 1449-16084 could not be used in developing these models because there were no internal calibration data found with it. This was unfortunate since a substantial number of lakes that might have been included in developing the models could not be used because their overlap on the 15th was on this unusable scene. Attempts to develop an internal calibration for this scene were unsuccessful. Unfortunately, we learned this after extensive efforts to develop meaningful clusters based on spectral data, and attempts to develop models relating spectral and chemical data, failed.

Using these models, a data base consisting of 14th and 16th data adjusted to the 15th, and raw 15th data, was prepared. Duplicates in the data base arising from the overlap lakes were removed, retaining original 15th data in preference to calculated values, except for scene 1449-16084 where only calculated values were used. For this latter reason, seven lakes (Bloomington, Springfield, Sanghris, Dawson, Evergreen, Goose (Sparland), and Wildwood) appearing in scene 1449-16084 could not be incorporated into the final data set. The raw and final sets are presented in Appendix Table A-1.

TABLE 7. REGRESSION MODELS USED TO ADJUST MULTISPECTRAL SCANNER DATA FOR OCTOBER 14 AND 16 TO OCTOBER 15, 1973

Dependent Variable	Regression Constant	Regression Coefficient	Independent Variable	R^2	Standard Error of Regression	Degrees of Freedom: Regression, Residual
Models for Adjusting the October 14th Data						
GRN15	0.5580	0.9683	GRN14	0.8226	2.0807	1,13
RED15	-1.1481	1.0161	RED14	0.9279	1.2853	1,13
IR115	0.9823	0.9473	IR114	0.9221	1.0811	1,13
IR215	1.6842	0.8822	IR214	0.9210	0.8931	1,13
Models for Adjusting the October 16th Data						
GRN15	12.4990	0.7291	GRN16	0.9445	0.6952	1,5
RED15	6.3859	0.7781	RED16	0.9918	0.4725	1,5
IR115	7.6123	0.6159	IR116	0.9464	0.8927	1,5
IR215	3.5378	0.6340	IR216	0.8652	0.7306	1,3

Trophic Indices Development

A multiplicity of classificatory schemes has evolved to group and rank lakes. Examples of some approaches to lake typology are found in Lueschow et al. (1970), Rawson (1956, 1960), Margalef (1958), Hansen (1962), Jarnefelt (1958), Larkin and Northcote (1958), Moyle (1945, 1946), Pennak (1958), Round (1958), Whipple (1898), Winner (1972), Zafar (1959), Beeton (1965), Donaldson (1969), Uttormark and Wall (1975), Gerd (1957), and Taylor et al. (in press). Hutchinson (1957, 1967) has reviewed many of the attempts to arrange lakes into orderly systems. The term "classification" is often used in the restricted sense of placing entities into distinct groups, thereby excluding arrangements showing no distinct division (e.g., ordination). The term is used here in the broader context suggested by Sneath and Sokal (1973) and includes ordination.

Lacustrine trophic state is a multidimensional concept and amenable to analysis by multivariate statistical techniques (e.g., cluster analysis, principal component analysis). Multivariate techniques minimize the personal bias often present when data are examined for groups and rankings are developed. They are of particular value in situations where large numbers of objects or parameters are to be classified. Principal components analysis can be used to develop trophic state indices.

Principal components analysis, an ordination technique, may be used to reduce the dimensionality of a multivariate system by representing the original attributes as functions of themselves. The main object is to summarize most of the variance in the system with a lesser number of "artificial" variates (i.e., principal components).

The computation of principal components can be undertaken using either a covariance matrix (S) or a p x p matrix of Pearson product-moment correlation coefficients (r). Use of the r-matrix is indicated when the variates are measured in different units (e.g., grams and meters). Computation of the r-matrix principal components involves the extraction of eigenvalues (characteristic or latent roots) and eigenvectors (characteristic or latent vectors). The eigenvalues are a set of p nonzero, positive, scalar quantities. The sum of the eigenvalues of the r-matrix is the trace of the matrix, which is equal to the number of dimensions in the original system (i.e., the number of variates, p). The rank of the matrix is equal to p.

Normalized eigenvectors give the attribute-space (A-space) coordinates of an orthogonal set of axes known as the principal axes. The normalized eigenvectors are comonly designated as principal components. The first principal component of the observations of the p-variates $X_1,\ldots,X_p$ is the linear compound

$$Y_j = a_{1j} X_1 + \ldots + a_{pj} X_p$$

whose coefficients are the elements of the eigenvector associated with the jth largest eigenvalue extracted from the r-matrix. The jth eigenvalue is a measure of the variance of the jth principal component.

The proportion of the total sample variance in the cloud of dimensionless standard scores attributable to any component is found by dividing its eigenvalue by p. The first principal component has the innate property of explaining the greatest proportion of the sample variance with each successive component explaining progressively smaller amounts of the total sample variance. Frequently, a consequence of the decreasing order of the variance is that $K < p$ dimensions will adequately summarize the variability of the original variates, $X_1,\ldots,X_p$. The first three components generally account for most of the variation, thereby permitting the ordination of the subjects in one-, two-, and three-dimensional (3-D) space. All of the dispersion in the data can be accounted for by using p dimensions, but this negates the analysis objective, which is the reduction of dimensionality or, as Seal (1964) stated, the "... parsimonious summarization of a mass of observations."

The principal components of N p-variate observations are defined geometrically as "... the new variates specified by the axes of a rigid rotation of the original response coordinate system into an orientation corresponding to the directions of maximum variance in the sample scatter configuration" (Morrison 1967). The normalized eigenvectors give the directions of the new orthogonal axes, and the eigenvalues determine the lengths (i.e., variance) of their respective axes. The coordinate system is expressed in standard units (zero mean, unit variance) when the components are extracted from the r-matrix. Figure 49 is a hypothetical bivariate example of the geometrical meaning of principal components. Detailed descriptions of the theoretical and computational aspects of principal components are found in Hotelling (1933a, 1933b, 1936), Anderson (1958), and Morrison (1967).

Principal components analysis was used to develop two trophic indices for the 31 Illinois water bodies sampled by the National Eutrophication Survey. The first index (PC1F5) uses the fall sampling values (Appendix Table A-2) for five trophic indicators: CHLA, ISEC, COND, TPHOS, and TON. The second index (PC1Y5) is generated using sampling-year mean values (Appendix Table A-3) for the same trophic indicators. The same methodology was employed in the development of both indices. The methodology is briefly explained below using the fall trophic index generation for illustrative purposes. The raw trophic indicator data (Appendix Tables A-2 and A-3) for the 31 NES-sampled lakes are skewed and were, therefore, natural log (LN)-transformed to give a distribution more closely approximating a normal one. The transformed indicator data are identified as LNCHLA, LNISEC, LNCOND, LNTPHOS, and LNTON. The data matrix was further standardized by attributes using the relationship

$$z_{ij} = (x_{ij}-\bar{x}_i)\ s_i$$

where

z = standardized value for attribute i of observation j (i.e., lake)

x_{ij} = LN-transformed value of attribute i of observation j

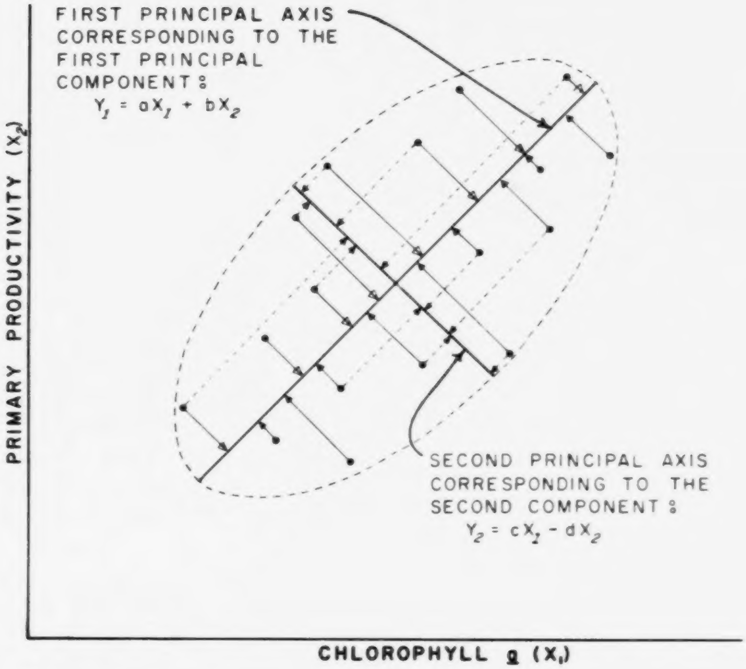

FIRST PRINCIPAL AXIS CORRESPONDING TO THE FIRST PRINCIPAL COMPONENT:
$Y_1 = aX_1 + bX_2$
SECOND PRINCIPAL AXIS CORRESPONDING TO THE SECOND COMPONENT:
$Y_2 = cX_1 - dX_2$
PRIMARY PRODUCTIVITY (X_2)
CHLOROPHYLL a (X_1)

Figure 49. Geometrical interpretation of the principal components for a hypothetical bivariate system.

Principal components may be interpreted geometrically as the variates corresponding to the orthogonal principal axes of observation scatter in A-space. The elements of the first normalized eigenvector (i.e., coefficients of the first principal component) define the axis that passes through the direction of maximum variance in the scatter of observations. The associated eigenvalue corresponds to the length of the first principal axis and estimates the dispersion along it. The second principal component corresponds to the second principal axis, the length of which represents the maximum variance in that direction. In our example, the first component accounts for most of the dispersion in the data swarm, and the original 2-dimensional system could be summarized in one dimension with little loss of information. The new variate value (PC1) for each lake is obtained by evaluating the first component

$$Y_1 = aX_1 + bX_2$$

The PC1 for each lake in one-dimensional A-space is its coordinate on the first component axis, which is shown diagrammatically by projecting each observation to the principal axis (modified from Brezonik and Shannon 1971).

$\bar{x}_i$ = the mean of attribute i

s_i = standard deviation of attribute i.

Eigenvectors and eigenvalues were then extracted from the associated correlation matrix (Table 8) and displayed in Table 9. Next, the first normalized eigenvector was evaluated for each of the 31 lakes, resulting in 31 trophic index (PC1F5) values, one for each water body. The PC1F5 value defines a water body's position on the first principal axis. The correlation coefficients, eigenvectors, and eigenvalues for the sampling-year trophic index (PC1Y5) are found in Tables 10 and 11, respectively. The resultant trophic index values for the 31 NES water bodies are found in Table 12.

TABLE 8. R-MODE PEARSON PRODUCT-MOMENT CORRELATION MATRIX OF FIVE TROPHIC STATE INDICATORS*

	CHLA (LNCHLA)	COND (LNCOND)	ISEC (LNISEC)	TPHOS (UVTPHOS)	TON (LNTON)
CHLA (LNCHLA)	1.000 (1.000)	0.219 (0.405)	0.242 (0.479)	0.649 (0.593)	0.827 (0.758)
COND (LNCOND)		1.000 (1.000)	0.142 (0.124)	0.596 (0.459)	0.327 (0.400)
ISEC (LNISEC)			1.000 (1.000)	0.444 (0.641)	0.370 (0.407)
TPHOS (LNTPHOS)				1.000 (1.000)	0.836 (0.771)
TON (LNTON)					1.000 (1.000)

*Correlations computed using mean data values of the fall sampling period for 31 NES-sampled water bodies. Numeric values enclosed by parentheses are correlation coefficients for natural log-transformed data.

Index values for 145 Illinois lakes were calculated from regression models developed from 22 of the NES lakes (LANDSAT data were available for only 22 NES lakes). In these models the trophic indices, derived from principal components analyses, were taken as the dependent variables and the LANDSAT MSS bands (or some variation thereof) were the independent variables. The data for the 22 NES lakes were used to develop the models. These models, found in "Trophic Indicator and Index Estimation" were then used to estimate trophic state index values for the entire set of 145 lakes.

TABLE 9. NORMALIZED EIGENVECTORS AND EIGENVALUES*

Eigenvector Number	LNCHLA	LNCOND	LNISEC	LNTPHOS	LNTON	Eigenvalue	Variance (%)	Cumulative Variance (%)
1	0.480	0.325	0.385	0.513	0.502	3.085	61.70	61.70
2	0.029	0.764	-0.634	-0.099	0.065	0.887	17.74	79.44
3	0.470	-0.504	-0.505	-0.208	0.476	0.557	11.14	90.58
4	0.642	0.181	0.297	-0.570	-0.377	0.363	7.26	97.84
5	-0.368	0.156	0.327	-0.599	0.612	0.108	2.16	100.00
						5.000		

*Eigenvalues and eigenvectors calculated from correlation matrix values based on trophic indicator data collected during the fall sampling period from 31 water bodies.

TABLE 10. R-MODE PEARSON PRODUCT-MOMENT CORRELATION MATRIX OF FIVE TROPHIC STATE INDICATORS*

	CHLA (LNCHLA)	COND (LNCOND)	ISEC (LNISEC)	TPHOS (LNTPHOS)	TON (LNTON)
CHLA (LNCHLA)	1.000 (1.000)	0.382 (0.439)	0.292 (0.412)	0.559 (0.622)	0.937 (0.807)
COND (LNCOND)		1.000 (1.000)	0.028 (-0.033)	0.422 (0.254)	0.360 (0.399)
ISEC (LNISEC)			1.000 (1.000)	0.443 (0.699)	0.275 (0.312)
TPHOS (LNTPHOS)				1.000 (1.000)	0.652 (0.699)
TON (LNTON)					1.000 (1.000)

*Correlations computed using sampling year-mean values for 31 NES-sampled water bodies. Numeric values in parentheses are correlation coefficients for the natural log-transformed data.

All of the computational aspects of trophic state index development were executed on a Control Data Corporation digital computer (CDC 3300) at Oregon State University using the Statistical Interactive Programming System (SIPS). A detailed explanation of SIPS and its operation is found in Guthrie et al. (1973).

Surface Area Estimation

The nominal size of a LANDSAT-1 MSS pixel is 57 meters by 79 meters, resulting in an areal coverage of 0.4503 hectares per pixel. As indicated earlier in this study, the surface area of a water body is defined by pixels having IR2 levels of 28 or less. The total surface area of a water body is calculated by summing the number of pixels having DN values within the above range (Appendix Table A-1) and then multiplying by the appropriate conversion factor. During the CCT preprocessing phase, the MSS data were resampled, resulting in pixels having nominal edge measurements of 80 m and an area of 0.6400 ha. The value of 0.6400 was used as the multiplication factor to convert water body IR2 pixel summations to surface area in hectares (Appendix Table A-1).

Side overlap coverage (October 14 and 15, October 15 and 16) was available for 22 Illinois water bodies. This self-pairing situation permitted the comparison of surface area estimates derived from LANDSAT data collected on consecutive days.

TABLE 11. NORMALIZED EIGENVECTORS AND EIGENVALUES*

Eigenvector Number	LNCHLA	LNCOND	LNISEC	LNTPHOS	LNTON	Eigenvalue	Variance (%)	Cumulative Variance (%)
1	0.519	0.269	0.375	0.514	0.504	2.926	58.52	58.52
2	0.182	0.703	-0.617	-0.258	0.160	1.127	22.54	81.06
3	-0.278	0.639	0.434	0.166	-0.546	0.562	11.24	97.30
4	-0.630	0.002	-0.362	0.639	0.253	0.265	5.30	97.60
5	-0.473	0.160	0.399	-0.483	0.598	0.120	2.40	100.00
						5.000		

*Eigenvalues and eigenvectors calculated form correlation matrix values based on sampling-year trophic indicator mean values for 31 water bodies.

TABLE 12. TROPHIC STATE INDICES AND RANKINGS FOR 31 NES-SAMPLED ILLINOIS WATER BODIES

Name of Water Body	Serial Number	PCIF5	(Rank)	PCIY5	(Rank)	NES	(Rank)
Baldwin	105	-1.74	(5)	-2.00	(3)	504	(2)
Bloomington	71	-1.00	(13)	-1.30	(8)	296	(16)
Carlyle*	14	-0.78	(14)	-0.90	(12)	345	(9)
Cedar*	55	-2.67	(1)	-2.89	(1)	528	(1)
Charleston*	16	0.78	(21)	0.02	(19)	225	(25)
Coffeen	94	-2.52	(2)	-2.55	(2)	454	(3)
Crab Orchard*	127	-0.22	(18)	0.14	(20)	347	(8)
Decatur*	73	-0.51	(16)	-0.17	(17)	201	(28)
DePue*	3	2.61	(30)	2.41	(29)	139	(31)
East Loon*	53	-0.55	(15)	-0.77	(15)	399	(5)
Fox*	60	0.67	(20)	1.68	(25)	212	(26)
Grass*	61	1.71	(26)	1.84	(26)	244	(20)
Highland-Silver	77	-1.76	(4)	-0.77	(13)	229	(23)
Holiday*	51	0.86	(22)	1.22	(22)	247	(19)
Horseshoe	131	1.31	(23)	2.43	(30)	313	(14)
Long*	52	2.59	(29)	1.98	(27)	195	(29)
Lou Yaeger	95	-1.38	(6)	-0.77	(14)	241	(21)
Marie*	62	1.43	(24)	0.33	(21)	303	(15)
Old Ben Mine*	32	2.38	(28)	1.55	(23)	240	(22)
Pistakee*	65	1.52	(25)	1.63	(24)	253	(18)
Raccoon*	80	-1.01	(12)	-0.48	(16)	330	(12)
Rend*	29	-1.19	(10)	-1.13	(9)	442	(4)
Sangchris	11	-1.89	(3)	-1.48	(5)	369	(6)
Shelbyville*	114	-1.35	(7)	-1.62	(4)	339	(10)
Slocum*	54	4.56	(31)	4.31	(31)	210	(27)
Springfield	112	-1.21	(9)	-1.09	(10)	283	(17)
Storey*	50	-0.47	(17)	-1.07	(11)	333	(11)
Vandalia*	27	-1.13	(11)	-1.32	(7)	323	(13)
Vermilion	122	-0.09	(19)	-0.16	(18)	227	(24)
We-Ma-Tuk*	33	-1.33	(8)	-1.35	(6)	367	(7)
Wonder*	69	2.33	(27)	2.29	(28)	183	(30)

*Used in the development of regression models for the estimation of trophic state using LANDSAT MSS bands as the independent variables.

DATA ANALYSIS APPROACH

Regression and cluster analysis are two techniques that were employed to explore the relationships suspected to exist between and within the remotely sensed and contact-sensed data sets.

Regression Analysis

MSS data presented as false-color or gray-scale imagery provide immediate visual recognition, not only of structural features such as water bodies, land surfaces, and vegetation, but also of gradations within and between such features. Expressed as spectral density histograms, information is derived about the evenness of the distribution of reflected radiation, without regard to the spatial distribution of the features giving rise to the pattern. Using clustering techniques, which will be described later, items such as lakes may be conveniently grouped together in physically significant ways solely on the basis of their reflectance patterns. All of these techniques need to utilize only the information inherent in the MSS data themselves to produce significant results.

In environmental monitoring studies such as this on lake trophic state, MSS data by themselves are of limited use. Rather, the scientist needs to use this readily available data to estimate physical, chemical, and biological parameters in lakes. To make these estimates, regressions are developed from a set of lakes for which concurrent contact-sensed and MSS data are available.

Regression is a statistical term describing the relationship of a dependent variable (Y) to one or more independent variables (X). Regression has many uses. In converting MSS data from the 14th or 16th of October to the 15th, for example, regression was used to effect a change of scale. Regression was also used to develop predictors or estimators of Y, for given values of X, as described below.

While several statistical methods for developing regression models exist, least-squares analysis is most commonly employed. According to Snedecor and Cochran (1967), three assumptions are made about the relation between Y and X in univariate models. First, for each value of X there is a normal distribution of Y from which a sample value of Y is taken at random. Second, the population of Y's corresponding to the selected value of X has a mean μ, which lies on the straight line

$$\mu_{y \cdot x} = \alpha + \beta x$$

where $x = X - \overline{X}$

α = the value of the population mean corresponding to $x = 0$

β = the slope of the line which is the incremental change in Y per unit change in X.

Third, the standard deviation, $\sigma_{y \cdot x}$, of Y about the mean is the same for all values of Y. Then

$$Y = \alpha + \beta X + \epsilon$$

where ϵ = a random variable drawn from normal population with mean 0 and standard deviation $\sigma_{y \cdot x}$.

This model assumes that all of the measured error, ϵ, is associated with the dependent variable, Y; that is, X is measured without error. When X is also subject to measurement error, such as with the MSS data of concern here, the measurement of X is X', where $X' = X + \delta$ and δ is the measurement error in X. Thus, the true model is

$$\begin{aligned} Y &= \alpha + \beta\ (X-\bar{X}) + \beta\ (\delta-\bar{\delta}) + \epsilon \\ &= \alpha + \beta X + \partial + \epsilon \end{aligned}$$

That is, the second assumption of the original model is not met by the MSS data used. In several environmental situations for which comparisons have been made for the two models, the models give essentially identical results. While the theoretical assumptions are not rigorously met by the available data, no practical differences are expected as long as it is recognized that the correlation coefficients developed here are slight overestimates compared to those that would be developed from the true model [see Schaeffer et al. (1974) for additional discussion and references].

Multiple regression models may be used to estimate trophic indicator and index values (chlorophyll a, Secchi depth, total phosphorus, total organic nitrogen, fall trophic index, and the year trophic index) from LANDSAT MSS data. Analogous to the development of univariate models, the least-squares multiple regression model can be written

$$Y = \beta_0 + \beta_1\ (X_1 - \bar{X}_1) + \beta_2\ (X_2 - \bar{X}_2) + \ldots + \beta i(X_i - \bar{X}_i) + \epsilon$$

where $X_1, X_2, \ldots, X_i$, and Y are jointly normally distributed. Then "... for each fixed set of values of $X_1, \ldots, X_i$, a population of Y's exist whose mean is given ..."by this equation (Dunn and Clark 1972). The first stage in developing trophic indicator and index models involved transformation and standardization of the contact-sensed (i.e., NES) and MSS date-adjusted data to give distributions more closely approximating that of a normal distribution with a mean of zero and unit variance. As used by Boesch (1977) and followed here, transformations in the strictest sense "... are alterations to the attribute scores ..." of entities without reference to the range of scores (e.g., logarithmic, arc sine, and square root functions). According to Boesch (1977), "standardizations are alterations which depend on some property of the array of scores under considerations." Because the data sets are small, highly dispersed, and skewed, this was a challenging task, requiring much trial and error.

Next, the actual models were developed by stepwise multiple regression using the date-corrected MSS bands as independent variables and trophic indicators and trophic indices as dependent variables. (A large number of "new" independent and dependent variables, "created" through a variety of techniques (e.g., log transformation, ratios, standardization), were examined during the modeling effort.) The regression was usually carried about two stages above that of maximum change in the multiple correlation coefficient (R) or its square (R^2). At this point the regression was backstepped until the most parsimonious model was reached. Selection of a particular model was made after an examination of the multiple correlation coefficient, mean residual square, significance of the regression and individual regression coefficients, number of independent variables, and scatter in the residuals for several models. A thorough discussion of the analysis and selection of variables in multiple regression is available in Hocking (1976).

Regressions were developed using the Statistical Interactive Programming System (SIPS) on a CDC 3300 digital computer located at Oregon State University (Rowe and Barnes 1976). With the particular regression subsystem used, it was discovered that the last-added independent variable was not necessarily the first removed in the backstepping mode (Hocking 1976). The subsystem was consistent in generating a particular model in this fashion, and the statistics for the chosen model could be confirmed by independent calculation. The three sets of models in Table 15 were developed in this manner. These models were used to estimate the values of trophic indicators and trophic indices for 145 Illinois water bodies. The estimated values were then used to rank the 145 water bodies.

Cluster Analysis

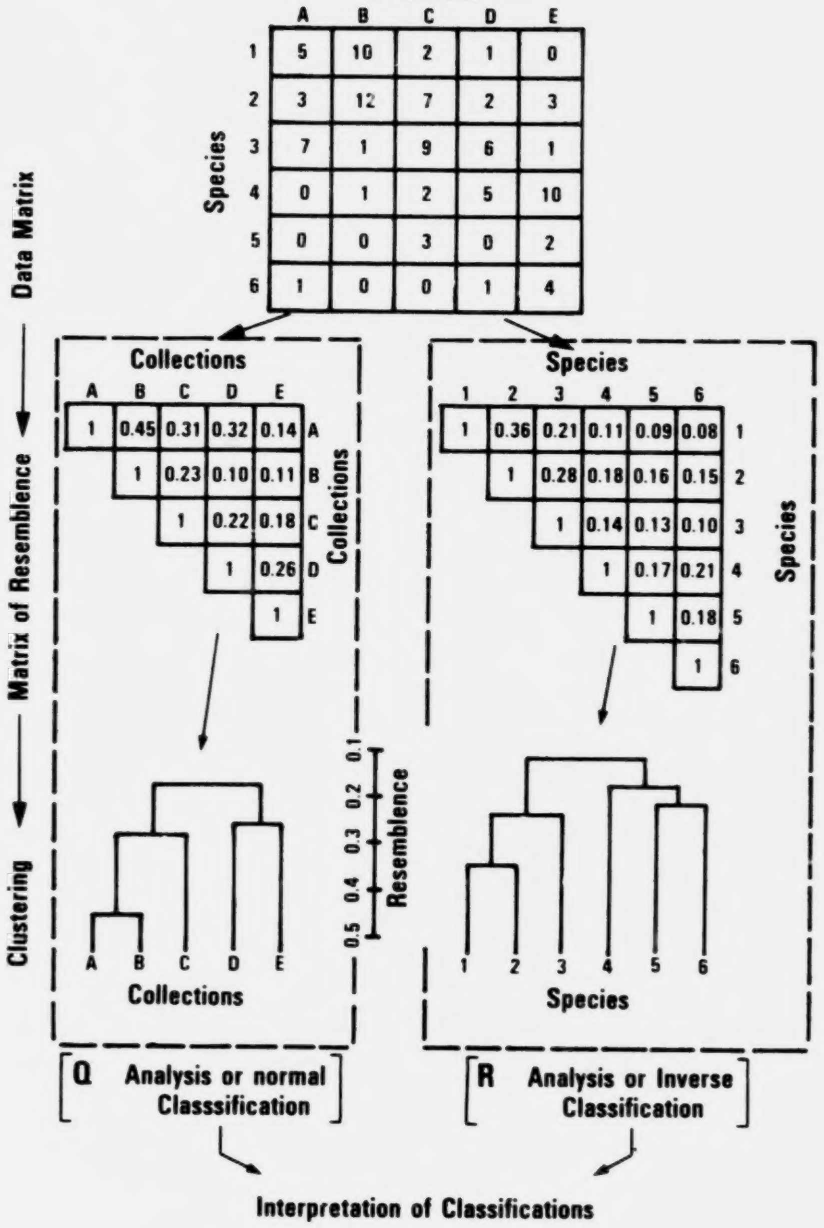
Boesch (1977) has recently written an excellent review of the application of numerical classification in ecological investigations of water pollution. Excerpts from his description of numerical classification are given below:

> "In simplest terms, classification is the ordering of entities into groups or sets on the basis of the relationships of their attributes. Classification is an important biological process which must predate man, but the science of classification has had a fairly recent and parallel development in several disciplines (Sokal 1974)....
>
> "Numerical classification or cluster analysis encompasses a wide variety of techniques for ordering entities into groups on the basis of certain formal pre-established criteria rather than on subjective and undefined conceptions. Numerical classifications have certain advantages over subjective classifications, notably: (1) they can be based on a much larger number of attributes than is allowed by human mental capacity; and (2) once the classificatory criteria are set, their results are repeatable by any investigator studying the same data set.

"It is important to distinguish classification from several other processes and analyses. First, the process of "identification," involving the allocation of additional unidentified entities to the most appropriate class, once such classes have been established (Dagnelie 1971, Sneath and Sokal 1973, Sokal 1974), is excluded from classification. . . . The optimal splitting of a continuous into a discontinuous series (Clifford and Stephenson 1975), is here considered a case of classification. Secondly, various multivariate analyses other than numerical classification may be applied to ecological data. These include, in addition to various regression and correlation approaches, a broad group of techniques known as ordination. In ordination the relationships among entities are expressed in a simplified spatial model of few dimensions, with no attempt to group or draw boundaries between classes (Pielou 1969, Whittaker 1967, Whittaker and Gaich 1973, Sneath and Sokal 1973, Orloci 1975). Ordination includes such techniques as principal components analysis, factor analysis, principal coordinates analysis, correspondence analysis, and multidimensional scaling.

"To orient the reader ..., a brief description of the chain of procedures in numerical classification is in order. Numerical classifications are generally directed by a set of algebraically expressed criteria (an algorithm). This chain of operations begins with the original data, in one or more forms which may be further transformed to conform to certain preconditions. In ecological applications the original data are generally in the form of a matrix of some measure of abundance of each species in a series of collections (See Figure 50).

"From the original or transformed data matrix most numerical classifications then require the computation of a resemblance measure between all pairs of entities being classified. This is a numerical expression of the degree of similarity, or, conversely, dissimilarity, between the entities on the basis of their attributes. In ecology, the entities being classified may be collections (representing sites, stations, or temporal intervals) with species content as the attributes. This may be referred to as a normal classification as opposed to an inverse classification of species as entities with their presence or abundance in the collections as attributes (Williams and Lambert 1961). 'Normal' or 'inverse' are synonymous with the widely used terms 'Q analysis' and 'R analysis', respectively. However, the Q/R distinction has been confused in the past (Ivimey-Cook, Proctor, and Wigston 1969) and the normal/inverse inverse terminology is fast becoming standard in ecology....



Collections
Species
Data Matrix
Matrix of Resemblence
Clustering
Collections
Collections
Species
Species
Resemblence
0.1
0.2
0.3
0.4
0.5
A
B
C
D
E
Collections
1
2
3
4
5
6
Species
Q Analysis or normal Classsification
R Analysis or Inverse Classification
Interpretation of Classifications

Species	A	B	C	D	E
1	5	10	2	1	0
2	3	12	7	2	3
3	7	1	9	6	1
4	0	1	2	5	10
5	0	0	3	0	2
6	1	0	0	1	4

A	B	C	D	E	Collections
1	0.45	0.31	0.32	0.14	A
	1	0.23	0.10	0.11	B
		1	0.22	0.18	C
			1	0.26	D
				1	E

1	2	3	4	5	6	Species
1	0.36	0.21	0.11	0.09	0.08	1
	1	0.28	0.18	0.16	0.15	2
		1	0.14	0.13	0.10	3
			1	0.17	0.21	4
				1	0.18	5
					1	6

Figure 50. Sequence of procedures in numerical classification (modified from Boesch 1977). (The Illinois water bodies were classified using LANDSAT MSS bands or LANDSAT estimated trophic indicators as "species", i.e., attributes).

> "Matrices of inter-entity resemblance measures are usually required to perform normal or inverse analyses. These matrices are symmetrical in that one corner is the mirror image of the other across the 'self-match' diagonal and thus it is necessary to display only half of the matrix, ... as the excluded portion is repetitous.... From the resemblance matrix one can go further and seek to group entities into groups on the basis of their patterns of resemblance....This is the essence of clustering.

Many clustering concepts and methods are described in the literature (Sneath and Sokal 1973, Anderberg 1973). Although algorithms have been developed for many clustering methods, the investigator is often forced to select from a very limited number because he lacks access to computers with the necessary operational software. In biological studies, the most commonly employed strategies for finding clusters are those that can be described by the acronym SAHN (sequential, agglomerative, hierarchic, nonoverlapping) (Sneath and Sokal 1973). Several SAHN clustering methods are found in Table 13.

TABLE 13. SOME SAHN CLUSTERING METHODS*

Cluster Method	Synonyms
Single linkage	Nearest neighbor Minimum method
Complete linkage	Furthest neighbor Maximum method
Average linkage	
Arithmetic average	
Unweighted (UPGMA)	Group average
Weighted (WPGMA)	
Centroid	
Unweighted centroid	Centroid
Weighted centroid	Median

*Adapted from Sneath and Sokal 1973

The complete linkage (also called maximum or furthest neighbor) method of clustering was selected for this project, primarily on the basis of availability. The complete linkage method may be described as an exclusive, intrinsic, hierachical, agglomerative, combinatorial approach to clustering (Figure 51).

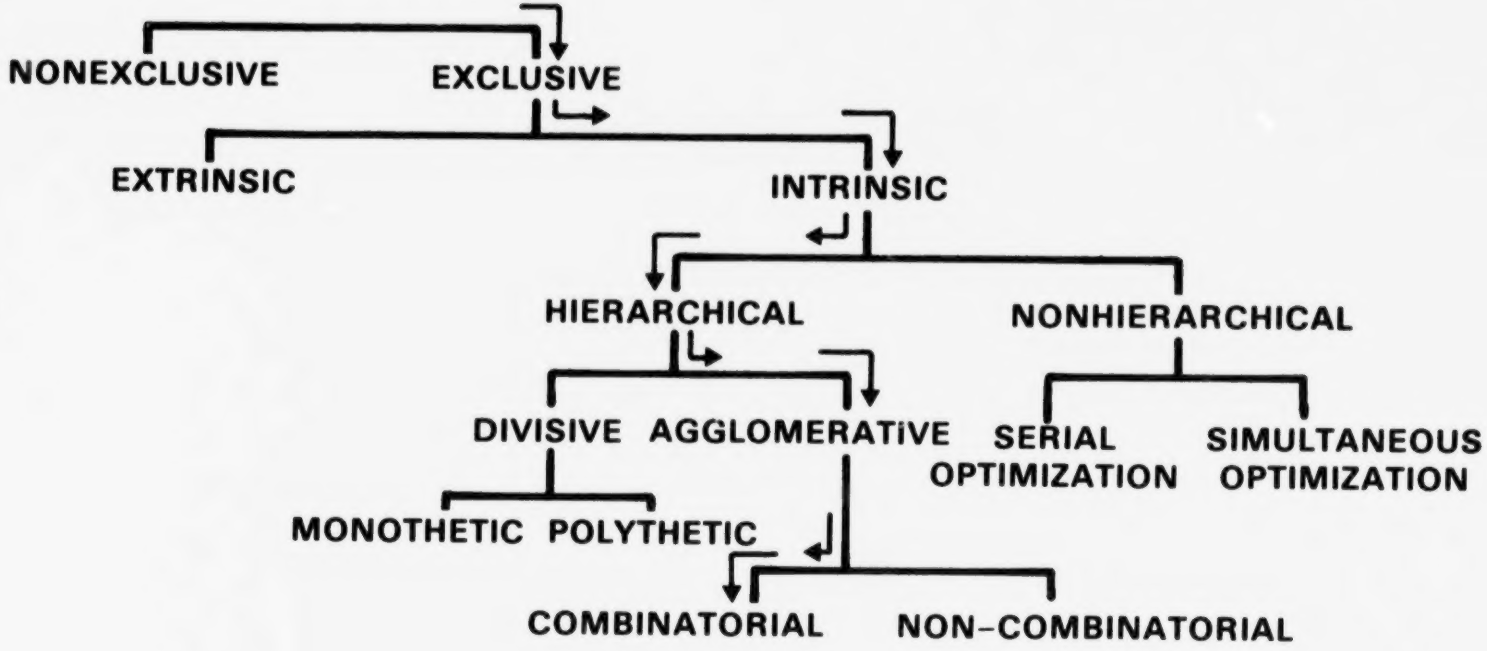

NONEXCLUSIVE
EXCLUSIVE
EXTRINSIC
INTRINSIC
HIERARCHICAL
NONHIERARCHICAL
DIVISIVE
AGGLOMERATIVE
SERIAL OPTIMIZATION
SIMULTANEOUS OPTIMIZATION
MONOTHETIC
POLYTHETIC
COMBINATORIAL
NON-COMBINATORIAL

Figure 51. Dichotomized scheme depicting the salient properties of clustering methods (modified from Boesch 1977 and Williams 1971). Complete linkage properties are interconnected by the arrow-defined pathway.

Although this report will not detail the above description of the complete linkage method (see Sneath and Sokal 1973, Boesch 1977, Anderberg 1973), it bears mentioning that the process is one of progressive fusions. Clustering proceeds "...by forming one cluster for each observation in the analysis. The two closest clusters are combined into one cluster, then the two closest of the new set of clusters are combined into a cluster, and so forth.... The distance between two clusters is defined to be the maximum distance between an observation in one cluster and an observation in the other cluster" (Barr et al. 1976).

Squared Euclidian distance (Δ^2) was selected as the resemblance measure (dissimilarity coefficient) between lakes. As with the clustering method, selection was made on the basis of availability. When working in an attribute space (A-space) of p orthogonal dimensions, Euclidian distance is the linear distance between any pair of entities (e.g., lakes) in that space. The distance between two entities is computed as the square root of the sum of the squared differences of the entity-paired attribute values

$$\Delta_{jk} = [\sum_{i=1}^{p} (X_{ij} - X_{ik})^2]^{\frac{1}{2}}$$

where Δ_{jk} = Euclidian distance between lake J and K

X_{ij} = the value of the ith attribute for lake J

X_{ik} = the value of the ith attribute for lake K

p = the number of attributes.

If two entities are identical in terms of their attributes, they will occupy the same position in p-dimensional A-space and the Euclidian distance between them will be zero. As the distance between entities increases, the disparity between them increases (Sneath and Sokal 1973). Distance is the complement of similarity.

The use of Euclidian distance (or its square) as a measure of resemblence has much intuitive appeal. It is relatively easy to grasp through the use of algebraic and geometric techniques (Figure 52). Recalling from geometry that the Pythagorean theorem for right triangles states that the square of the length of the hypotenuse is equal to the sum of the squares of the lengths of the two remaining sides, or (using the notation in the upper part of Figure 52)

$$c^2 = a^2 + b^2$$

it follows that the length of the hypotenuse (distance between Point A and Point B) may be defined as

$$c = (a^2 + b^2)^{\frac{1}{2}}$$

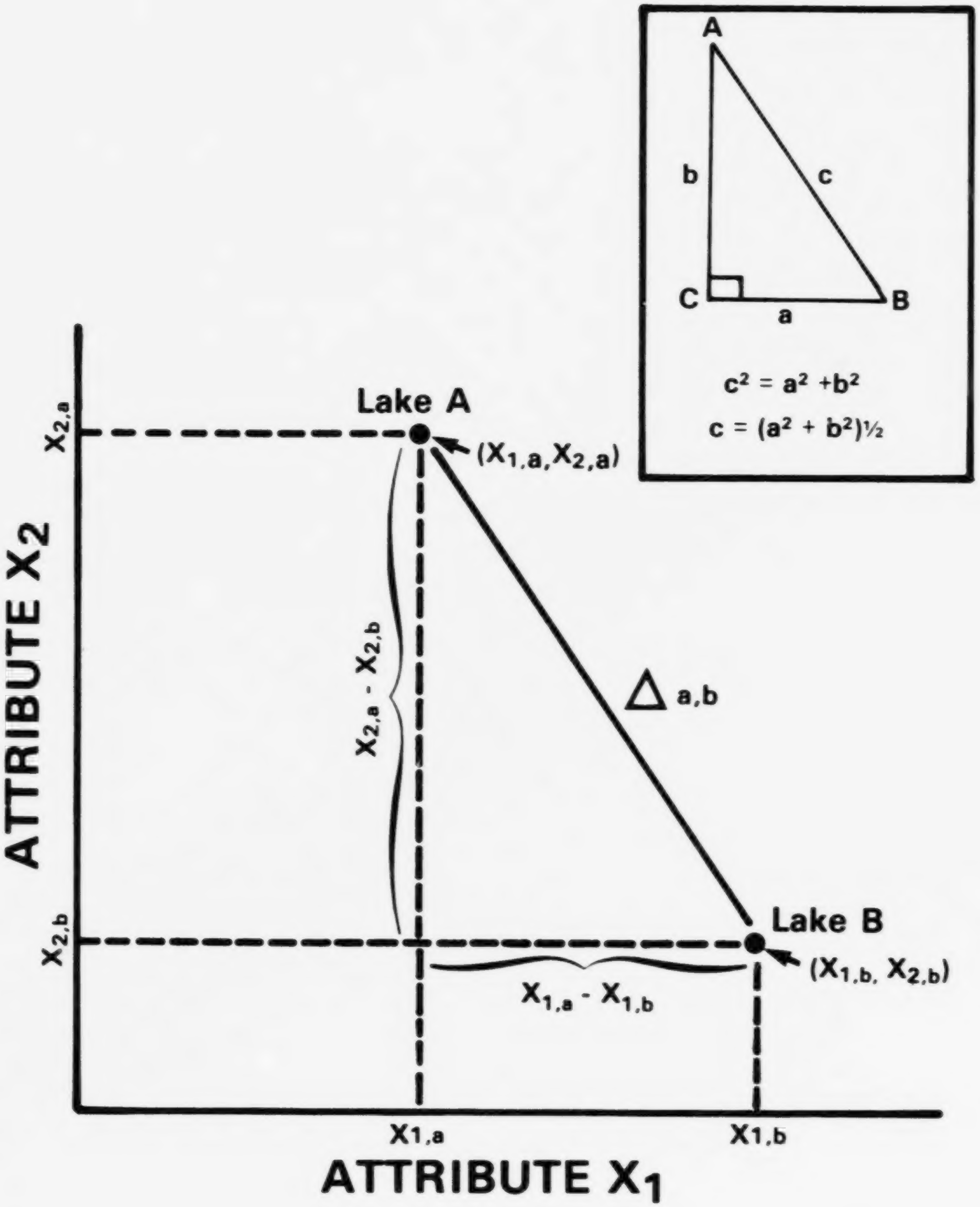

A
b
c
C
B
a
$c^2 = a^2 + b^2$
$c = (a^2 + b^2)^{1/2}$
Lake A
$(X_{1,a}, X_{2,a})$
$X_{2,a}$
ATTRIBUTE X_2
$X_{2,a} - X_{2,b}$
$\Delta_{a,b}$
Lake B
$(X_{1,b}, X_{2,b})$
$X_{2,b}$
$X_{1,a} - X_{1,b}$
$X_{1,a}$
$X_{1,b}$
ATTRIBUTE X_1

Figure 52. Geometric aspects of Euclidian distance between two entities (i.e., lakes) defined by coordinates in two-dimensional attribute space (A-space).

Using different notation (lower portion of Figure 52), the Pythagorean theorem is extended to two lakes, A and B, whose locations in two-dimensional attribute space (A-space) are defined by the coordinate pairs ($X_{1,a}$, $X_{2,a}$) and ($X_{1,b}$, $X_{2,b}$), respectively. The squared Euclidian distance between the lakes may be described as

$$\Delta_{ab}{}^2 = |X_{1,a} - X_{1,b}|^2 + |X_{2,a} - X_{2,b}|^2$$

where | | refers to "absolute magnitude" and is employed to eliminate the use of negative distances. The squaring of differences also ultimately eliminates the negative distance aspect and thus the equation may be rewritten as:

$$\Delta_{ab}{}^2 = (X_{1,a} - X_{1,b})^2 + (X_{2,a} - X_{2,b})^2$$

The Euclidian distance (Δ_{ab}) between the two lakes is described by

$$\Delta_{ab} = (\Delta_{ab}{}^2)^{\frac{1}{2}}$$

and will either have or lack units depending upon which preclustering procedures are used. If, for example, the attribute data in the data matrix were standardized (mean of zero, unit variance), the Euclidian distance would be dimensionless. On the other hand, using the LANDSAT MSS bands as the attributes and foregoing transformations and standardizations (i.e., using MSS band raw data), the Euclidian distance would be measured in digital number (DN) levels.

Figure 53 illustrates the geometric aspects of three lakes (A, B, and C) in three-dimensional A-space. In this case squared Euclidian distance between Lake A and Lake B is computed as

$$\Delta_{ab}{}^2 = |X_{1,a} - X_{1,b}|^2 + |X_{2,a} - X_{2,b}|^2 + |X_{c,a} - X_{3,b}|^2$$

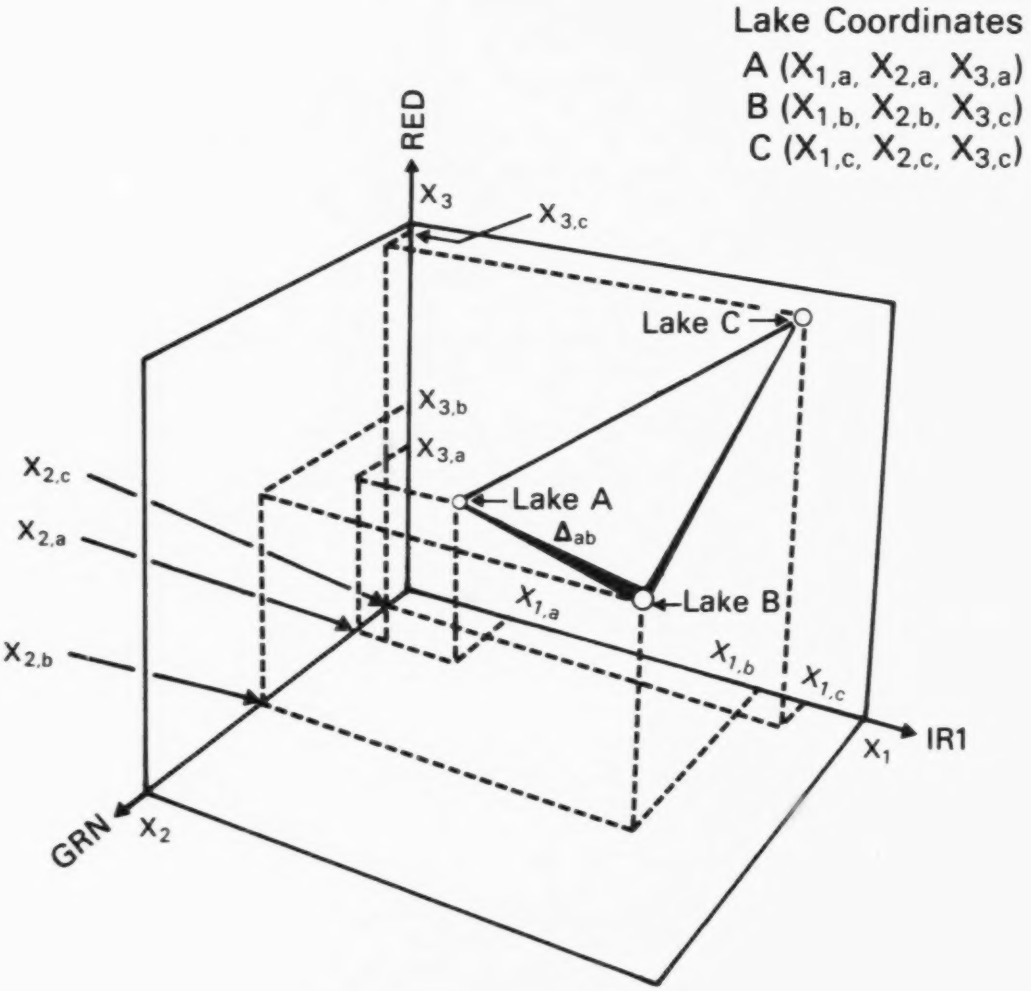
or

$$= (X_{1,a} - X_{1,b})^2 + (X_{2,a} - X_{2,b})^2 + (X_{3,a} - X_{3,b})^2$$

and

$$\Delta_{ab}{}^2 = (\Delta_{ab}{}^2)^{\frac{1}{2}}$$

It is difficult to visualize the geometry of four-dimensional A-space and it can not be depicted graphically because of the orthogonal axes requirement. However, it is possible to extend most geometric theorems of three-dimensional spaçe to p dimensions in Euclidian hyperspace; this can be demonstrated algebraically (Sneath and Sokal 1973). Thus, the Euclidian distance dissimilarity measure is not limited to three dimensions by theoretical constraints.


Lake Coordinates
A (X1,a, X2,a, X3,a)
B (X1,b, X2,b, X3,c)
C (X1,c, X2,c, X3,c)
RED
X3
X3,c
Lake C
X3,b
X3,a
X2,c
X2,a
X2,b
Lake A
Δab
Lake B
X1,a
X1,b
X1,c
X1
IR1
GRN
X2

$$\Delta_{ab}^{2} = (X_{1,a} - X_{1,b})^{2} + (X_{2,a} - X_{2,b})^{2} + (X_{3,a} - X_{3,b})^{2}$$

$$\Delta_{ab} = (\Delta_{ab}^{2})^{1/2}$$

Figure 53. Geometric and computational aspects of Euclidian distance between three entities (i.e., lakes) defined by coordinates in three-dimensional attribute space (A-space). [In this example, the attributes are three LANDSAT bands (GRN, RED, IR1). The attributes could be three trophic indicators (e.g., chlorophyll a, Secchi depth, total phosphorus) (adapted from Boesch 1977 and Sneath and Sokal 1973).]

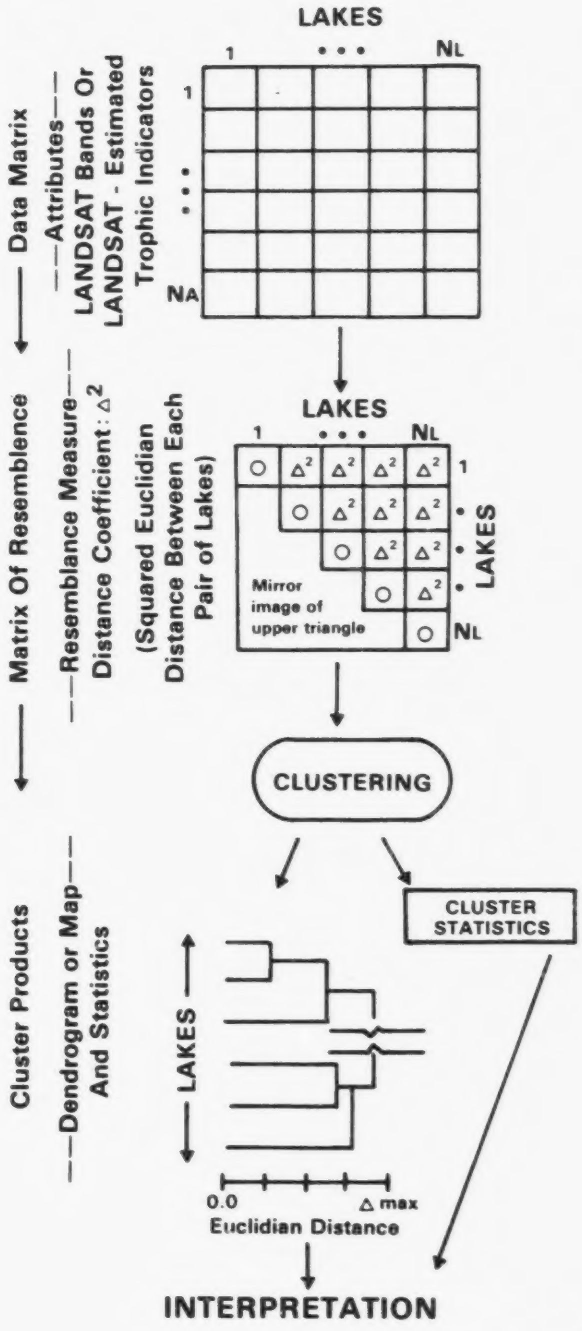
As indicated earlier, the complete linkage clustering method was employed using squared Euclidian distance as the measure of resemblance. The (Δ_{jk}^2) sequence of procedures is illustrated in Figure 54. While many clustering "runs" were made, only the results for two, made on 145 Illinois water bodies in A-space, will be interpreted in the discussion in Section 7 of this report. These runs are:

1. Four-band LANDSAT clustering -- A-space of four dimensions defined by LANDSAT GRN, RED, IR1, and IR2 bands. Date-adjusted MSS data were used without standardization or transformation.

2. LANDSAT-estimated four trophic indicator clustering -- A-space of four dimensions defined by the trophic indicators CHLA, TPHOS, TON, and SEC. Trophic indicator values were estimated from regression models developed from LANDSAT MSS-trophic indicator relationships elucidated for 22 NES-sampled lakes. The values for each trophic indicator were standardized (mean of zero, unit variance) prior to the computation of the resemblance matrix.

The actual clustering was accomplished using two different computer programs. The first program, CLUSTER, was developed by Barr et al. (1976) as part of the SAS 76 statistics program package. It uses the clustering scheme described by Johnson (1967). The cluster "map" generated by the program was found to be physically bulky, difficult to visually interpret, and thus unsuitable for inclusion in this report. Fortunately, this program also generates a listing of the clusters and their respective members. A second program (also called CLUSTER) rewritten by Keniston from programs by Keniston, Faruqui, and Carkin (Keniston 1978) was used to generate products (e.g., dendrograms or phenograms) of a more desirable nature. This program was run on a Control Data Corporation (CDC) CYBER 73 digital computer at Oregon State University. The dendrograms were then generated on a Gerber Model 1000 flatbed plotter, an "off-line" device, using the tape output from the CYBER 73.

The outputs of a clustering program represent an attempt to simplify complex data sets. Numerical classification per se does not provide an ecological interpretation of the products. Post-clustering analyses aimed at the interpretation of the dendrograms are presented in Section 7 of this report.



Data Matrix
Attributes
LANDSAT Bands Or
LANDSAT - Estimated
Trophic Indicators
LAKES
1
NL
1
NA
Matrix Of Resemblence
Resemblance Measure
Distance Coefficient: Δ²
(Squared Euclidian
Distance Between Each
Pair of Lakes)
LAKES
1
NL
Δ²
Mirror
image of
upper triangle
1
LAKES
NL
CLUSTERING
CLUSTER
STATISTICS
Cluster Products
Dendrogram or Map
And Statistics
LAKES
0.0
Δ max
Euclidian Distance
INTERPRETATION

Figure 54. Sequence of procedures as applied to the numerical classification of Illinois water bodies.

SECTION 7

RESULTS AND DISCUSSION

As indicated in Section 1, the basic objective of this project was to classify, in the broad sense of the term, Illinois lakes and reservoirs as to trophic state. It was the original intention to include all Illinois lentic bodies with surface areas equal to or greater than 40 ha. This would have included the 31 NES-sampled lakes. A combination of circumstances (e.g., cloud cover, missing or defective MSS data) resulted in dropping approximately 40 of the proposed 179 lakes. The decrease in the number was partially offset by the inclusion of several water bodies with surface areas under 40 ha. The end result was the use of 22 NES-sampled water bodies in the development of the regression models. Rankings and classes were generated for 145 Illinois water bodies, including the 22 sampled by NES. Subsequent subsections of this section will discuss the results.

WATER BODY SURFACE AREA

Surface area estimates were made for 153 Illinois water bodies (Appendix Table A-1) including those found in scene 1449-16084, the scene without internal calibration data. As evidenced by Appendix Table A-1, side overlap lakes have two LANDSAT-derived area estimates, one for each consecutive day of satellite coverage. Two questions immediately come to mind: How precise are the consecutive day area estimates? How accurate are the estimated area values? Table 14 was prepared in response to these questions. The lakes included in this table are those for which side overlap coverage was available, excluding those from scene 1449-16084. Lake Senachwine was not included in the statistical calculations because its area estimate for October 16, 1973, is less than optimal, a consequence of a portion of the lake falling outside scene 1450-16140.

An indication of the precision of LANDSAT MSS-derived area estimates can be gained by examining the self-pairing estimates made for 21 water bodies. Ideally, the consecutive-day estimates for a particular water body would be the same, and indeed this is the case for three water bodies: Commonwealth Edison-Dresden Nuclear Lake (serial number 137), Lake Pinckneyville (serial number 99), and Snyders Hunting Club Lake (serial number 142). The difference between the self-paired estimates was computed as (A-B) where A is the area estimate of October 14 or 16 and B is the estimate of October 15. The mean difference for the water bodies is 0 ha with a sample standard deviation of 13 ha. The correspondence between the estimates A and B is very good, as demonstrated by Figure 55 and the area ratios (A/B) in Table 14.

TABLE 14. COMPARISON OF SURFACE AREA ESTIMATES FOR 22 ILLINOIS WATER BODIES HAVING LANDSAT SIDE OVERLAP COVERAGE (OCTOBER 14 AND 15 OR OCTOBER 15 AND 16, 1973)

		Area Estimates (ha)								
		LANDSAT Date		File*	Area Differences			Area Ratios		
Name	Serial Number	14th or 16th (A)	15th (B)	(C)	(A-B)	(A-C)	(B-C)	(A/B)	(A/C)	(B/C)
Carbondale	38	29	27	55	+ 2	- 26	- 28	1.07	0.53	0.49
Cedar**	39	72	77	728	- 5			0.94		
Commonwealth	137	460	460	526	0	- 66	- 66	1.00	0.88	0.88
DeQuoin	98	55	52	99	+ 3	- 44	- 47	1.06	0.56	0.52
Goose †	101	741	696	1143	+45	-402	-447	1.07	0.65	0.61
Goose (Village)	139	74	75	109	- 1	- 35	- 34	0.99	0.68	0.69
Kinkaid	40	855	876	1093	-21	-238	-217	0.98	0.78	0.80
McGinnis	20	114	102	127	+12	- 13	- 25	1.12	0.90	0.80
Murphysboro	37	47	54	58	- 7	- 11	- 4	0.87	0.81	0.93
Pierce	130	60	58	66	+ 2	- 6	- 8	1.03	0.91	0.88
Pinckneyville	99	49	49	67	0	- 18	- 18	1.00	0.73	0.73
Saganashkee	21	146	167	132	-21	+ 14	+ 35	0.87	1.11	1.26
Senachwine ‡	104	1209	1603	1346	---	----	----	----	----	----
Skokie Lagoons	22	80	84	76	- 4	+ 4	+ 8	0.95	1.05	1.11
Snyders Hunting	142	17	17	81	0	- 64	- 64	1.00	0.21	0.21
South Wilmington	140	99	101	41	- 2	+ 58	+ 60	0.98	2.42	2.46
Spring	4	137	135	106	+ 2	+ 31	+ 29	1.02	1.29	1.27
Spring Arbor	143	15	17	41	- 2	- 26	- 24	0.88	0.37	0.42
Summerset	186	94	92	115	2	- 21	- 23	1.02	0.82	0.80
Tampier	23	90	94	66	- 4	+ 24	+ 28	0.96	1.36	1.42
Thunderbird	173	38	42	45	- 4	- 7	- 3	0.91	0.84	0.93
Sum		3510	3505	4258						
Mean		167	167	213	0	- 40	- 42	0.99	0.90	0.92
Standard Error of Mean		51	50	73	3	23	25	0.02	0.10	0.10
Maximum Value		855	876	1143	45	58	60	1.12	2.41	2.46
Minimum Value		15	17	41	-21	-402	-447	0.87	0.21	0.21
Range		840	859	1102	66	460	507	0.25	2.21	2.25
Sample Standard Deviation					13	104	111	0.07	0.46	0.47

* Surface area values taken from IEPA data files.

** Cedar Lake was just filling in 1973. The file value is for 1977. The lake is not included in the calculations.

† Goose Lake (101) area difference (A-B) exceeds the sample standard deviation by more than three times.

‡ Senachwine (104) surface area data not included in calculations because a portion falls outside scene 1450-16140.

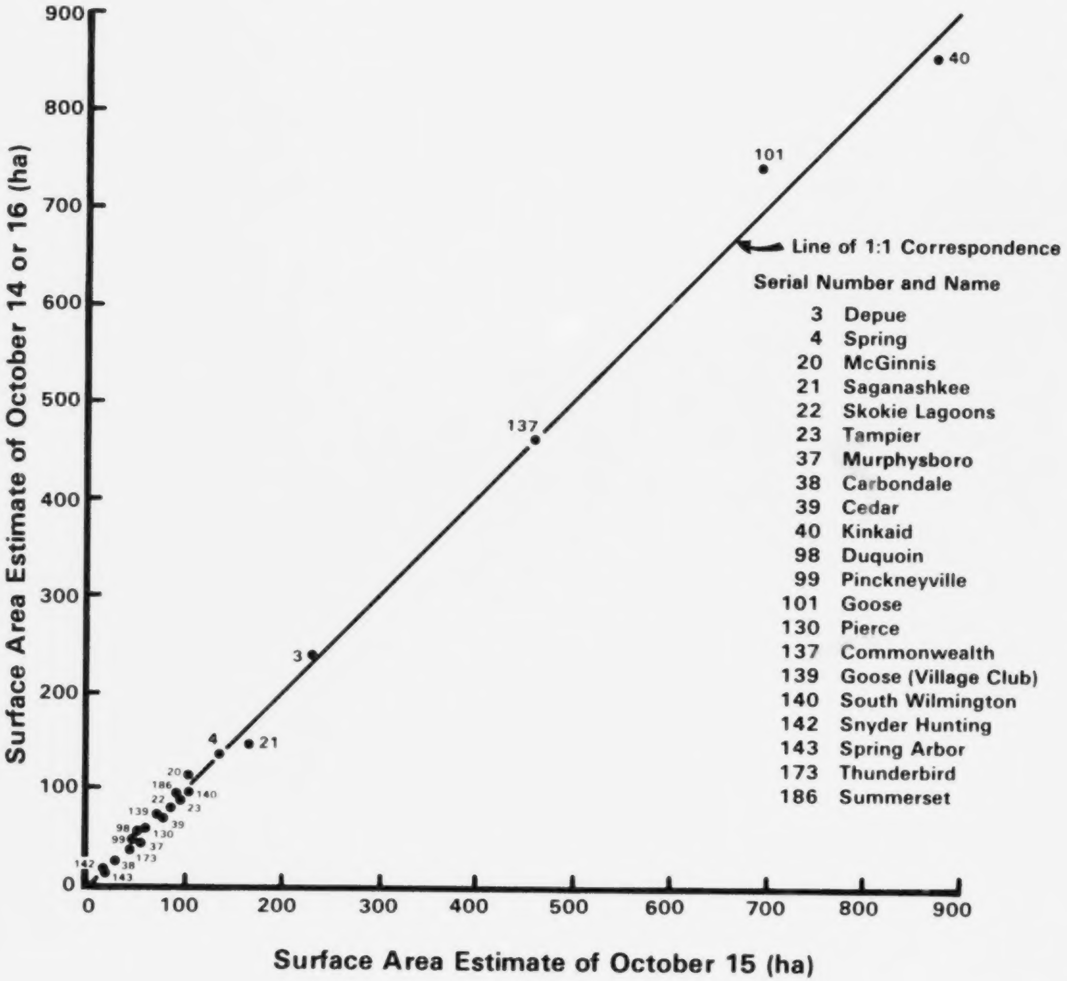


Figure 55. LANDSAT-derived consecutive-day surface area estimates for 21 Illinois water bodies.

The line in Figure 55 is defined by the ideal area ratio of 1:1; it is not a regression line generated from area data for the 21 water bodies. If the two area estimates for a particular water body are the same, the point representing the values would fall somewhere on the line. With a few exceptions, the points fall on or very close to the line. The area ratios (A/B) for several lakes are a source of some concern; these include McGinnis (1.12), Murphysboro (0.87), and Saganashkee (0.87). Assuming that the areal discrepancies are not a consequence of heavy rains or drawdown, several factors may be responsible for the variation in the estimates.

One such factor, probably the prime one, is atmospheric variability. Atmospheric path radiance can change markedly from one day to the next. For example, the intrinsic (independent of atmosphere) radiance may be the same for a lake for two consecutive LANDSAT flyovers. However, as viewed through the atmosphere by the satellite, the lake may exhibit an apparent change in its intrinsic radiance, a consequence of a change in path radiance. As path radiance increases, the apparent intrinsic radiance of most lakes will increase and the converse is also true. Thus, the DN values for the pixels representing a lake and surrounding terrain may change from day to day. As given previously, an IR2 level of 28 was used as the threshold between land and water features. If a pixel has an IR2 DN value of 0 to 28, inclusive, it was classified as water; if 29 to 255, it was labeled as nonwater. The IR2 DN threshold of 28 was treated as a rigid boundary. Increases in path radiance could result in an apparent emigration of pixels across the boundary, effectively reducing the number of pixels in the IR2 0 to 28 DN group defined as water. Decreases in path radiance could result in the immigration of more pixels to the IR2 0 to 28 DN group, leading to a larger surface area estimate.

In situations where water bodies are in juxtaposition and have poorly defined natural boundaries (e.g., flowages and backwaters), the judgment of the computer operator becomes the critical factor in separating the water bodies. In this case, the operator defines the location of the common boundary. He is not always able to duplicate the boundary's location in successive imagery. The situation is further complicated by maps that give conflicting locations for the boundary or, and this is more common, only name the bodies, leaving the map reader the task of defining boundaries. The common boundary problem can lead to different surface area estimates.

Illinois reservoirs tend to be long and narrow, with highly developed shoreline configurations (numerous fingers and bays). With so much land-water interface (Lake Sangchris, for example, has more than 160 km of shoreline), a substantial number of pixels will contain both land and water features. In many cases the land portion of the pixel may contribute enough energy to shift the pixel DN value above the water threshold. This could lead to an underestimation of lake surface area.

The accuracy of LANDSAT-derived area estimates is another point of prime concern. This concern can be best addressed by examining the LANDSAT area values in light of estimates derived from other time-proven techniques (e.g., aerial photography, surveying) employed concurrently with the LANDSAT flyover. The concurrent aspect of the contact-sensed data is important because lentic bodies are dynamic and can experience substantial changes in surface area. Prolonged dry spells, drawdown, large quantities of precipitation, outlet downcutting, flow control structures, and landfill projects can produce changes in surface area. Even in the case of concurrent acquisition of surface area data, the problem of defining the water-land interface exists. It would appear that defining the boundary of a lentic body on an aerial photograph or through survey is an easy task, and in some cases it is. However, more often the task of locating the interface is complicated by the presence of marshes or swamps that grade into a lake over distance. Where to "draw the line" becomes a problem that is left to the judgment of the photointerpreter, cartographer, or surveyor. Once this determination has been made and the requisite computations performed, an area estimate is entered into a data file. It is important to recognize the limitation of surface area figures taken from files.

Given the historical nature of this project -- NES sampled the water bodies prior to the formulation of the project protocol -- surface-area data were not readily available. This severely handicapped the project in making a detailed analysis of the accuracy of LANDSAT-derived surface estimates. However, realizing its limitations, a comparison was made using surface area figures taken from IEPA files (Table 14). For reservoirs, in most cases, the file values are estimates of the surface area at spillway level at the time of construction. However, in many cases the surface area at the spillway level has probably changed over time because of shoreline erosion, sedimentation, and other factors. Pool level elevations are not available for October 1973. An examination of Table 14 and accompanying Figures 56 and 57 suggests that the LANDSAT-derived values tend, on the average, to underestimate the IEPA values. A lot of scatter is apparent about the 1:1 line of correspondence. Hence, data of sufficient quality are not available to determine how well LANDSAT data, as processed, estimate the surface area of Illinois lakes.

It may well be that the LANDSAT area values are underestimates. Boland and Blackwell (1978), reporting on a study involving several Colorado lakes, indicate that LANDSAT area estimates were, on the average, about 1.2 percent under those estimated from concurrently acquired aerial photographs ($N = 8$). The Colorado data do not, however, prove that LANDSAT underestimates the surface area of Illinois water bodies.

The selection of the IR2 DN level of 28 as the water-land threshold value was made based on past experience and its intuitive appeal; it is a simple approach. As suggested by Blackwell and Boland (1978), it may be more appropriate to use the technique (or some variation) proposed by McCloy (1977). This technique, discussed in Section 6, may result in more precise and accurate estimates of surface area.

TROPHIC INDICATOR AND INDEX ESTIMATION

In order to obtain estimates of four trophic indicators (CHLA, SEC, TON, and TPHOS) and two multivariate trophic indices (PC1F5, PC1Y5) using LANDSAT MSS spectral data, three sets of multiple regression models were developed (Table 15). Initially, regressions were developed for the indicators and

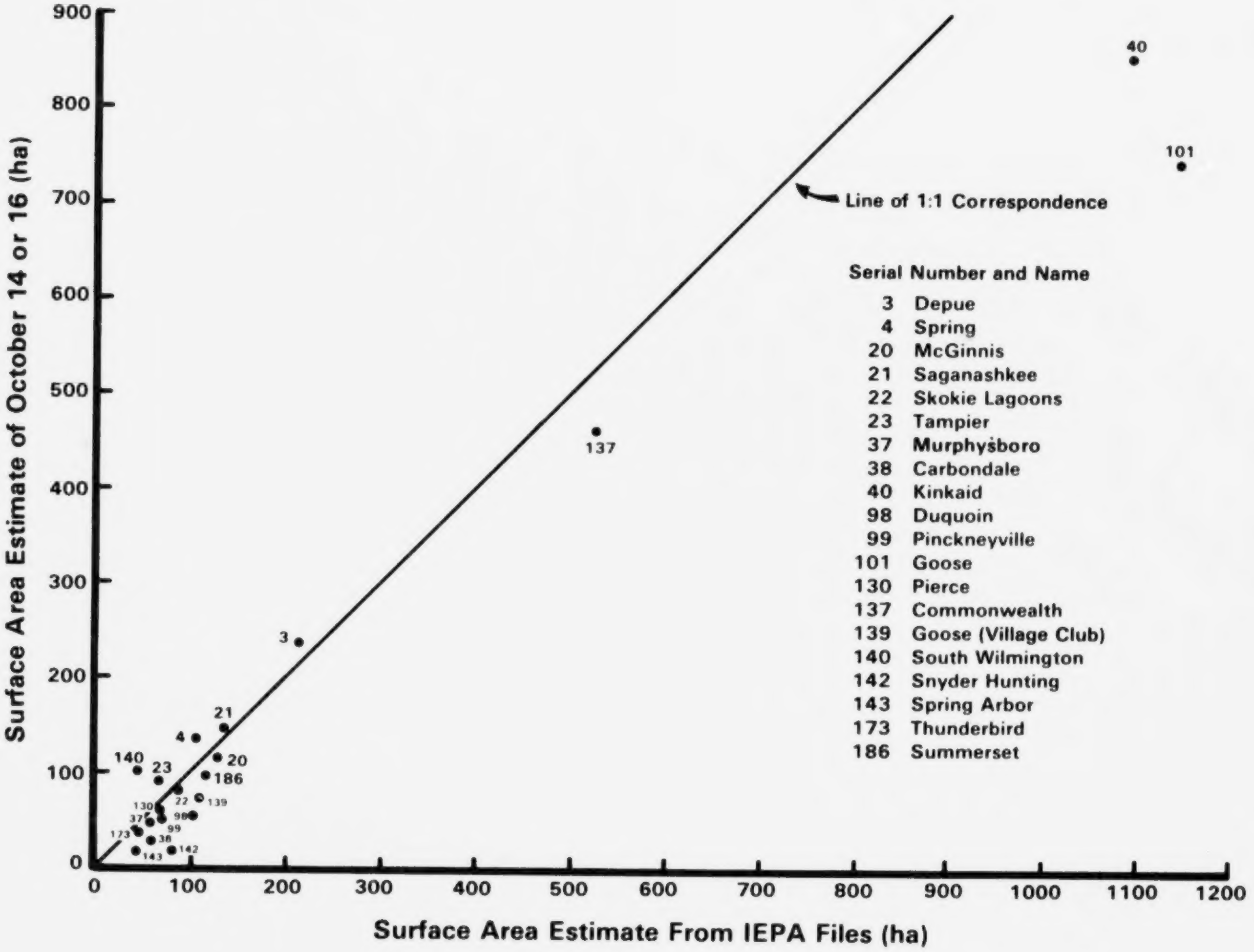


Figure 56. Comparison of October 14 and 16 LANDSAT-derived surface area estimates with IEPA file values for 20 Illinois water bodies.

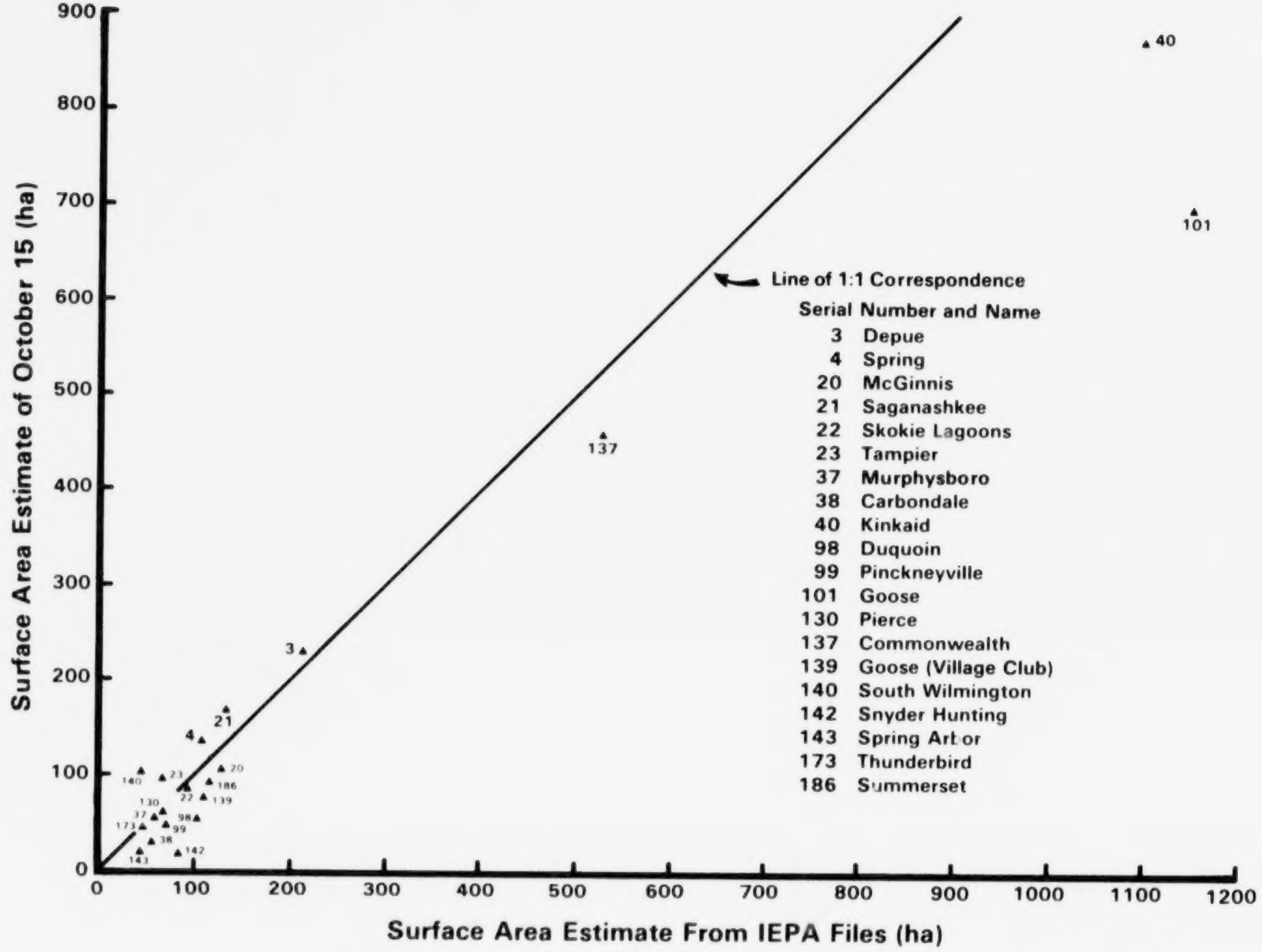


Figure 57. Comparison of October 15, 1973, LANDSAT-derived surface area estimates with IEPA file values for 20 Illinois water bodies.

TABLE 15. THREE SETS OF REGRESSION MODELS FOR THE ESTIMATION OF TROPHIC INDICATORS AND MULTIVARIATE TROPHIC STATE INDICES

	Model	Degrees of Freedom	Calculated F-Value	R^2x 100	Standard Error of Estimate
	Set One: Models based on LANDSAT MSS spectral bands and band ratios				
SEC =	-26.206 - 0.610 * GRN + 0.939 * RED + 17.246 * GRNRED + 1.276 * REDIR1 - 0.827 * IR1IR2	5,16	9.55	74.90	0.31
CHLA =	EXP (37.337 + 0.476 * GRN - 0.922 * RED -15.327 * GRNRED -8.079 * REDIR1 + 1.922 * REDIR2)	5,15	22.30	88.14	
TON =	[(X * X-1.) **2./ (4. * X * X)] where X is: -2.023 - 0.223 * GRN + 0.325 * IR1 + 3.117 * GRNRED + 0.826 * REDIR2	4,17	25.16	85.55	0.31
TPHOS =	{EXP[EXP (6.202 - 0.076 * IR1 -2.293 * GRNIR1 + 0.244 * GRNIR2)]}/100.	3,18	18.74	75.75	
PC1F5 =	(12.279 - 0.177 * IR1 - 4.631 * GRNIR1 + 0.572 * GRNIR2) **2.-3.	3,18	30.46	83.54	0.71
PC1Y5 =	12.782 - 0.193 * IR1 - 5.017 * GRNIR1 + 0.701 * GRNIR2) **2. -3.	3,18	39.32	86.76	

(continued)

TABLE 15. (continued)

Model	Degrees of Freedom	Calculated F-Value	R^2X 100	Standard Error of Estimate
Set Two: Models based on normalized LANDSAT spectral bands				
SEC = EXP[EXP (1.396 - 0.234 * SIR1 - 1.198 * LNSRED + 0.227 * SGRN + 0.200 * SIR2)] /100.	4,17		72.6	0.33
CHLA = [-34.677 - 12.735 * SIR1 - 16.209 * LNSIR2 - 5.304 * RED + 94.014 * LNSIR1]**2.	4,17		80.2	28.91
TON = {EXP[EXP(8.796 + 0.087 * SIR1 - 4.522 * RTSGRN + 0.647 * SGRN - 0.042 * SIR2)]}/100.	4,17		70.4	0.34
TPHOS = [1.173 + 1.407 * LNSIR1 - 1.682 * LNSGRN + 5.371 * RTSIR2 - 5.176 * LNSIR2]**5.	4,17		73.7	0.16
PC1F5 = 79.188 + 19.827 * LNSIR1 - 48.892 * SQRTSGRN + 5.399 * SGRN - 7.459 * LNSIR2	4,17		81.2	0.80
PC1Y5 = -10.922 - 5.041 * SIR1 - 9.384 * LNSIR2 - 2.276 * SGRN + 44.592 * LNSIR1	4,17		87.6	0.61

(continued)

TABLE 15. (continued)

Model	Degrees of Freedom	Calculated F-Value	R^2x 100	Standard Error of Estimate
Set Three: Models based on lake LANDSAT spectral ranks				
SEC = {EXP[EXP(1.552 - 0.006 * REDRK + 0.003 * IR2RK + 0.006 * GRNRK - 0.005 * IR1RK)]}/100.	4,17		59.0	
CHLA = [2.147 - 0.011 * GRNRK - 0.010 * IR2RK + 0.008 * RAT100 + 0.017 **IR1RK] **5.	4,17		74.0	
TON = {EXP[EXP(1.263 + 0.002 * IR1RK - 0.001 * GRNRK - 0.001 * IR2RK) **2.]}/100.	3,18		62.5	0.39
TPHOS = (0.697 + 0.005 * IR1RK - 0.003 * GRNRK - 0.001 * IR2RK) **5.	3,18		61.1	0.20
PC1F5 = 0.264 + 0.076 * IR1RK -0.043 * GRNRK - 0.030 * IR2RK	3,18		65.3	1.04
PC1Y5 = 0.304 + 0.076 * IR1RK - 0.040 * GRNRK- 0.038 * IR2RK	3,18		64.6	1.03

multivariate indices using contact-sensed and raw spectral data available from 22 NES-sampled lakes. In developing these models (Set One, Table 15) using stepwise regression, additional variates were created by taking the ratios of bands (i.e., green band to red band, GRNRED). The use of such ratios has precedent in similar studies (e.g., Boland 1976). While the models gave every appearance of having practical utility (e.g., high R^2, low standard error of estimate, good estimates of indicator and index values), when they were applied to the full set of 145 lakes major inconsistencies appeared. The inconsistencies were particularly obvious when the estimated values of the four trophic indicators for the 145 lakes were aggregated into a combined or composite rank for each lake and a list was generated displaying the lakes in ascending order of eutrophication.

To create this list, the estimated value for each trophic indicator (CHLA, TON, SEC, TPHOS) was replaced by its rank value. The rank values for the four indicators were summed to give a grand value for each of the 145 lakes, which were then ranked in ascending order according to the magnitude of the grand value. An examination of this list disclosed several seriously misclassified lakes. For example, Lake Calumet, a highly polluted water body, appeared near the top (best) of the list. These reversals were suspected to be the result of at least four causes.

First, although efforts were made to normalize the dependent (trophic indicator or multivariate index) parameter in developing the regression models, no effort was made to do this for the spectral data. This was not deemed important since, with the exception of the IR2, the bands showed an approximately normal distribution of data, with skew and kurtosis of about 0.0 and 3.0, respectively.

Second, although the IR2 band has the poorest discrimination, and the lowest information content of any of the bands, it weighed consistently and heavily in all of the models. When this band was excluded, the resulting models were statistically unsatisfactory. Thus, we are faced with the paradox of a poorly resolved factor contributing significantly to the predictive power of the regressions. Since, in at least some of the cases (e.g., Calumet), the IR2 intensity did not appear to vary to the extent or direction of the other bands, that is, did not increase as water quality deteriorated, the highly significant IR2 values would contribute nonlinearly to the estimates.

Third, it was recognized that the ratios used in developing the models contributed nonlinear components to the regressions. This effect, coupled with the nonlinearity contributed by the IR2, resulted in "linear" models with nonlinear components. Alternatively, the effect may be viewed as that of a p-dimensional plane operating in a nonorthogonal or bivalued p-dimensional hyperspace; that is, the model is a linear hyperplane cutting both curved and linear spaces.

Fourth, the spectral data for the subset of 22 water bodies used to develop the models cover a narrow range in relation to that of the full set of 145. Thus, while the models appear to operate well for lakes within this narrow band, they have very poor discrimination outside these limits.

Whether the failure to afford reasonable extrapolations is inherent in the data, as discussed above, or in the models, as suggested here, is moot since no simple corrections for these effects are apparent. Consequently, the project is constrained by these models to estimate trophic indicator and multivariate trophic index values only for lakes with LANDSAT MSS data that fall within the range of those for the 22-lake subset or to develop other models as will now be discussed.

In developing new models, it was imperative that the information about the full range of the whole set be included in the subset used for developing the regressions. To accomplish this, the spectral data for the subset were standardized by dividing each observation by the standard deviation for that band for the entire set of 145. The models (Set Two, Table 15) that were developed using standardized spectral data gave better estimates of trophic indicator and index values for the subset of 22 than did those constructed from the raw spectral data. Further, the estimates for the full set showed few reversals or non-linearities.

At least two problems were apparent with some of the individual trophic indicator and index estimates made from Set Two models. First, these models generated negative values for lakes with LANDSAT spectral data either much higher or much lower than the regression set, for Secchi and chlorophyll a, and total organic nitrogen and total phosphorus respectively. Unreasonably high estimates of Secchi depth were obtained from very low (or for the other indicators, for very high) spectral data values.

Trophic indicator estimates made for the 145 water bodies from the second set of models, when converted to ranks, gave ordered lists which were in reasonable agreement with expectation. Clusters developed from the estimated trophic indicator values appeared to have physical significance in that the clusters could be sequenced in a rough hierachy of trophic condition.

The third set of models was developed using data ranks in place of raw or normalized spectral data. To create the regression models (Set Three, Table 15), the normalized spectral data for the 145 lakes were sequenced in ascending order, and ranks were then assigned to each value for each of the four bands. Next the spectral ranks for the 22 NES lakes were extracted from the set of 145 and used to develop the third set of models defining statistical relationships between the remotely sensed data and ground truth. For Secchi depth, total organic nitrogen, and total phosphorus, highly significant correlations were developed using combinations of the four sets of ranked spectral data. Chlorophyll a presented a problem, however, in that this technique afforded statistically significant, but physically unimportant, models with poor predictive power. Careful examination of the results from the other models, clustering results from spectral data, and consideration of the interactions occurring between chlorophyll a and the high sediment loads present in many Illinois lakes suggested that some spectral ratio of the LANDSAT IR1 or IR2 and the red and green bands might make a statistically significant contribution to the model for chlorophyll a. For these reasons two ratios were developed, one between the RED and IR1 bands and the other, subsequently named RAT100, between the GRN and IR2 bands. The former was statistically insignificant when included as a regression variable, while the latter was highly significant. The use of the variable RAT100, defined as (GRNRK + IR2RK) / (GRNRK - IR2RK -1.), where GRNRK and IR2RK are a lake's rank for the set of 145, caused mathematical problems for Diamond Lake (serial number 57) and potential problems for Grass Lake (serial number 61), Swan Lake (serial number 93), and Pierce Lake (serial number 130). For the first lake the denominator of the ratio was zero, while for the other three it was either plus or minus 1, indicating that GRNRK = IR2RK. For these four lakes RAT100 was assigned a value of zero.

Trophic indicator and multivariate trophic index estimates generated from the Set Three models are in general agreement with the contact-sensed data for the 22 NES lakes (Table 16). The descriptive statistics for the actual and predicted values are in (subjectively) close agreement, thereby indicating that the models are capable of reproducing population, as well as point, information. The 95 percent confidence limits of the predicted values for the 22 NES lakes used in developing the Set Three regression models are within the range of the sample values (Table 17). These confidence limits are those obtained for each estimated point. They are not the same, being broader, as the standard error about the mean of the dependent variable.

The trophic indicator and index estimates for the full set of 145 Illinois lakes developed from the Set Three models are found in Appendix Table A-4. The population statistics for the full set are (subjectively) in agreement with those of the subset of NES lakes (Table 18). This is important for two reasons. First, it demonstrates that the NES lakes comprise a random subset; that is, they adequately reflect the variability of the population. Second, unlike the previous models (Sets One and Two), the predictive equations are essentially linear over the data range. Therefore, meaningful extrapolations can be made from the Set Three models.

While it is possible to gauge the accuracy of the trophic indicator and multivariate index estimates for the 22 NES lakes through an examination of the models' residuals, the necessary concurrent contact-sensed data are not available for the remaining 123 lakes, thereby preventing a similar comparison. However, the estimates for the full set appear to be "reasonable" for Illinois lakes.

IEPA sampled 72 of the 145 lakes during the summer of 1977. It is not appropriate to gauge the accuracy of the 1973 parameter estimates in terms of the 1977 field measurements. The 1973 data were collected in the middle of October. By contrast, the 1977 data were collected during the summer when the Secchi depth would be expected to be lower because of plankton biomass and recreational uses that suspend and resuspend particulate matter and intense agricultural activities that contribute substantially to the particulate load. Recognizing the limitations imposed by the dynamic nature of inland water bodies, a comparison was made for the 72 lakes using Secchi depth, a parameter common to both data sets. The mean Secchi depth values (N = 72) for 1973 and 1977 are 0.98 and 0.97 m, respectively. The product-moment correlation coefficient, significant at the 0.01 level, is 0.505. However, because the data were collected or estimated for different

TABLE 16. TROPHIC INDICATOR AND MULTIVARIATE TROPHIC INDEX OBSERVED, ESTIMATED, AND RESIDUAL VALUES FOR THE SET THREE REGRESSION MODELS

Name	Serial Number	SEC	$\widehat{\text{SEC}}$	SEC-$\widehat{\text{SEC}}$	CHLA	$\widehat{\text{CHLA}}$	CHLA-$\widehat{\text{CHLA}}$	TON	$\widehat{\text{TON}}$	TON-$\widehat{\text{TON}}$
Carlyle	14	0.48	0.42	0.06	19.9	10.3	9.6	0.742	0.598	0.144
Cedar	55	2.77	1.19	1.58	5.6	26.7	-21.1	1.105	1.160	-0.055
Charleston	16	0.25	0.27	-0.02	18.0	36.0	-18.0	1.200	1.308	-0.108
Crab Orchard	127	0.36	0.62	-0.26	46.7	26.5	20.2	0.843	1.010	-0.167
Decatur	73	0.46	0.29	0.17	21.4	48.6	-27.2	0.590	1.410	-0.820
DePue	3	0.15	0.25	-0.10	42.4	45.4	- 3.0	2.020	1.492	0.528
East Loon	53	0.91	0.85	0.06	26.8	25.8	1.0	1.380	1.225	0.155
Fox	60	0.36	0.35	0.01	37.4	46.5	- 9.1	0.970	1.252	-0.282
Grass	61	0.31	0.31	0.00	46.1	46.8	- 0.7	1.773	1.391	0.382
Holiday	51	0.46	0.43	0.03	67.0	37.6	29.4	1.200	1.477	-0.277
Long	52	0.31	0.44	-0.13	61.2	43.6	17.6	2.074	1.326	0.754
Marie	62	0.56	0.36	0.20	70.7	59.9	10.8	1.896	1.612	0.284
Old Ben Mine	32	0.48	0.57	-0.09	24.6	18.4	6.2	1.690	1.307	0.383
Pistakee	65	0.31	0.54	-0.23	66.5	33.5	33.0	1.635	1.142	0.493
Raccoon	80	0.41	0.31	0.10	10.6	19.6	- 9.0	0.900	0.856	0.044
Rend	29	0.61	0.58	0.03	15.6	18.0	- 2.4	0.971	0.854	0.117
Shelbyville	114	0.48	0.67	-0.19	12.8	15.4	- 2.6	0.595	0.828	-0.233
Slocum	54	0.31	0.34	-0.03	241.4	229.4	12.0	5.940	5.118	0.822
Storey	50	0.89	0.93	-0.04	30.0	30.4	- 0.4	0.980	0.898	0.082
Vandalia	27	0.71	0.89	-0.18	13.5	19.4	- 5.9	1.019	0.853	0.166
We-Ma-Tuk	33	1.07	0.62	0.45	8.3	5.0	3.3	0.588	0.820	-0.232
Wonder	69	0.46	0.31	0.15	198.0	157.5	40.5	1.788	2.068	-0.280

(continued)

TABLE 16. (continued)

Name	Serial Number	TPHOS	$\widehat{\text{TPHOS}}$	TPHOS-$\widehat{\text{TPHOS}}$	PC1Y5	$\widehat{\text{PC1Y5}}$	PC1Y5-$\widehat{\text{PC1Y5}}$	PC1F5	$\widehat{\text{PC1F5}}$	PC1F5-$\widehat{\text{PC1F5}}$
Carlyle	14	0.091	0.056	0.035	-0.90	-1.22	-0.32	-0.78	-1.58	-0.80
Cedar	55	0.053	0.135	-0.082	-2.89	-0.36	2.53	-2.67	-0.26	2.41
Charleston	16	0.207	0.349	-0.142	0.02	1.03	1.01	0.78	1.27	0.49
Crab Orchard	127	0.114	0.138	-0.024	0.14	-0.14	-0.28	-0.22	-0.19	0.03
Decatur	73	0.143	0.272	-0.129	-0.17	1.10	1.27	-0.51	1.11	1.62
DePue	3	0.499	0.413	0.086	2.41	1.36	-1.05	2.61	1.64	-0.97
East Loon	53	0.087	0.176	-0.089	-0.77	-0.17	0.60	-0.55	0.06	0.61
Fox	60	0.212	0.200	0.012	1.68	0.88	-0.80	0.67	0.71	0.04
Grass	61	0.347	0.226	0.121	1.84	0.75	-1.09	1.71	0.77	-0.94
Holiday	51	0.173	0.238	-0.065	1.22	0.63	-0.59	0.86	0.78	-0.08
Long	52	0.785	0.187	0.598	1.98	0.46	-1.52	2.59	0.46	-2.13
Marie	62	0.286	0.326	-0.040	0.33	1.47	1.14	1.43	1.51	0.08
Old Ben Mine	32	0.930	0.328	0.602	1.55	0.11	-1.44	2.38	0.74	-1.64
Pistakee	65	0.216	0.156	0.060	1.63	0.12	-1.51	1.52	0.08	-1.44
Raccoon	80	0.145	0.155	-0.010	-0.48	-0.03	0.45	-1.01	-0.11	0.90
Rend	29	0.065	0.083	-0.018	-1.13	-0.96	0.17	-1.19	-1.03	0.16
Shelbyville	114	0.063	0.083	-0.020	-1.62	-1.20	0.42	-1.35	-1.18	0.17
Slocum	54	1.330	1.425	-0.095	4.31	4.92	0.61	4.56	5.15	0.59
Storey	50	0.125	0.174	-0.049	-1.07	-0.69	0.38	-0.47	-0.34	0.13
Vandalia	27	0.175	0.122	0.053	-1.32	-1.02	0.30	-1.13	-0.80	0.33
We-Ma-Tuk	33	0.103	0.171	-0.068	-1.35	-1.15	0.20	-1.33	-0.63	0.70
Wonder	69	0.423	0.468	-0.045	2.29	1.96	-0.33	2.33	2.18	-0.15

TABLE 17. COMPARISON OF THE RANGE OF NES SAMPLE VALUES WITH THE 95 PERCENT CONFIDENCE LIMITS OF PREDICTED VALUES

	SEC		CHLA		TPHOS		TON	
	OBS*	PRED**	OBS*	PRED**	OBS*	PRED**	OBS*	PRED**
Carlyle	0.4-0.6	0.2-1.3	9.8-38.8	1.1-47.7	0.076-0.119	0.004-0.318	0.88-1.24	0.32-1.30
Cedar	2.8	0.4-4.8	5.6	5.6-88.1	0.029-0.093	0.020-0.534	0.98-1.31	0.58-2.72
Charleston	0.3	0.1-0.7	11.2-24.9	8.6-109.3	0.172-0.229	0.080-1.093	0.69-1.50	0.65-3.11
Crab Orchard	0.3-04	0.3-1.9	29.4-77.6	5.9-81.8	0.071-0.257	0.023-0.507	0.56-1.83	0.53-2.16
Decatur	0.5	0.1-0.7	6.3-33.9	13.5-135.7	0.111-0.173	0.061-0.868	0.36-0.94	0.71-3.31
DePue	0.2	0.1-0.6	42.4	11.4-129.0	0.499	0.098-1.234	2.02	0.72-3.58
E. Loon	0.9	0.3-3.0	26.8	5.3-83.5	0.085-0.089	0.031-0.638	1.25-1.84	0.61-2.85
Fox	0.3-0.4	0.2-0.9	24.3-80.6	12.2-133.7	----	0.037-0.703	----	0.63-2.93
Grass	0.3	0.1-0.8	37.7-54.6	12.9-132.2	0.283-0.438	0.047-0.758	1.27-2.29	0.70-3.26
Holiday	0.3-0.6	0.2-1.2	66.5-67.5	9.1-113.2	0.152-0.212	0.048-0.799	0.97-1.36	0.72-3.58
Long	0.3	0.2-1.2	60.7-61.8	11.4-125.8	0.744-0.828	0.035-0.659	1.76-2.24	0.66-3.11
Marie	0.3-0.8	0.2-0.9	59.6-81.9	17.4-161.0	0.262-0.318	0.076-1.000	1.61-2.18	0.79-3.93
Old Ben Mine	0.5	0.2-1.9	24.6	2.9-70.5	0.920-0.940	0.065-1.115	1.54-1.84	0.62-3.31
Pistakee	0.3	0.2-1.6	59.7-73.3	8.2-100.4	0.201-0.232	0.027-0.565	1.54-1.73	0.59-2.57
Racoon	0.4-0.5	0.1-0.8	3.1-18.1	3.4-69.7	0.073-0.299	0.023-0.604	0.74-1.06	0.45-1.89
Rend	0.5-0.8	0.3-1.7	10.3-21.7	3.3-62.2	0.047-0.082	0.010-0.357	0.76-143	0.46-1.81
Shelbyville	0.3-0.9	0.3-2.0	5.3-26.3	2.7-55.5	0.023-0.128	0.010-0.355	0.39-1.02	0.45-1.74
Slocum	0.3	0.1-1.2	241.4	73.7-571.0	1.330	0.394-3.947	5.94	1.70-21.27
Storey	0.8-0.9	0.3-3.5	16.2-43.8	5.5-108.2	0.053-0.321	0.030-0.638	0.86-1.48	0.47-2.23
Vandalia	0.6-0.9	0.3-3.0	10.1-18.0	3.6-67.5	0.044-1.020	0.019-0.476	0.75-1.89	0.46-1.81
We-Ma-Tuk	0.9-1.2	0.2-2.0	5.2-11.4	0.4-28.2	0.066-0.177	0.025-0.681	0.45-0.51	0.43-1.86
Wonder	0.3-0.6	0.1-0.8	188.0-211.0	47.0-416.9	0.363-0.477	0.119-1.270	0.97-2.25	0.95-5.38

*OBS = Observed sample range
**PRED = 95% limits for predicted value (point estimate)

TABLE 18. SUMMARY STATISTICS FOR SET THREE (SPECTRAL RANK) REGRESSION MODELS

Parameter	N	Mean	Median	Maximum	Minimum	Standard Deviation	Skew	Kurtosis
GRNRK	22	64.68	64.00	136.00	8.00	33.46	0.41	2.65
GRNRK	145	73.00	73.00	145.00	1.00	42.00	0.00	1.80
REDRK	22	69.82	63.50	123.00	11.00	28.30	0.26	2.88
REDRK	145	73.00	73.00	145.00	1.00	42.00	0.00	1.80
IR1RK	22	55.45	52.00	135.00	6.00	32.59	0.54	2.82
IR1RK	145	73.00	73.00	145.00	1.00	42.00	0.00	1.80
IR2RK	22	40.86	31.00	104.00	4.00	29.31	0.83	2.70
IR2RK	145	73.00	73.00	145.00	1.00	42.00	0.00	1.80
RAT100	22	5.75	2.29	48.50	-11.94	13.90	2.08	6.70
RAT100	145	2.71	1.42	81.67	-71.75	18.24	1.11	9.73
$\underline{\text{SEC}}$	22	0.60	0.46	2.77	0.15	0.54	3.22	13.58
$\widehat{\text{SEC}}$	22	0.52	0.44	1.17	0.25	0.25	1.02	3.20
residuals	22	-0.07	-0.01	0.27	-1.60	0.38	-3.16	13.45
$\widehat{\text{SEC}}$	145	0.76	0.48	7.41	0.17	0.79	4.67	35.28
$\underline{\text{CHLA}}$	22	49.30	28.40	241.4	5.60	59.11	2.35	7.63
$\widehat{\text{CHLA}}$	22	45.31	31.94	227.8	5.00	50.86	2.69	9.50
residuals	22	-3.98	-0.50	27.6	-40.48	17.13	-0.33	2.73
$\widehat{\text{CHLA}}$	145	30.60	24.67	229.4	0.91	29.92	3.29	18.58
$\underline{\text{TON}}$	22	1.44	1.15	5.94	0.59	1.11	3.13	13.43
$\widehat{\text{TON}}$	22	1.36	1.23	5.08	0.59	0.89	3.43	14.94
residuals	22	-0.09	-0.10	0.82	-0.86	0.39	0.04	3.03
$\widehat{\text{TON}}$	145	1.27	1.16	5.12	0.41	0.65	3.56	19.85
$\underline{\text{TPHOS}}$	22	0.30	0.17	1.33	0.05	0.33	1.96	6.10
$\widehat{\text{TPHOS}}$	22	0.27	0.18	1.42	0.05	0.28	3.38	14.60
residuals	22	-0.03	0.02	0.14	-0.60	0.20	-2.27	7.19
$\widehat{\text{TPHOS}}$	145	0.30	0.26	1.62	0.02	0.25	2.90	12.16
$\underline{\text{PC1F5}}$	22	0.46	0.23	4.56	-2.67	1.77	0.41	2.52
$\widehat{\text{PC1F5}}$	22	0.47	0.30	5.13	-1.60	1.42	1.48	6.25
residuals	22	0.00	0.22	2.13	-2.41	1.04	-0.02	3.24
$\widehat{\text{PC1F5}}$	145	0.48	0.60	5.15	-3.61	1.38	0.30	1.37
$\underline{\text{PC1Y5}}$	22	0.35	0.08	4.31	-2.89	1.72	0.30	2.56
$\widehat{\text{PC1Y5}}$	22	0.35	0.11	4.89	-1.24	1.38	1.53	6.27
residuals	22	0.00	-0.17	1.52	-2.53	1.03	-0.37	2.94
$\widehat{\text{PC1Y5}}$	145	0.13	0.20	4.92	-3.70	1.32	0.22	1.40

seasons it would be inappropriate to suggest that, overall, Secchi transparency has changed or, for that matter, remained the same.

Trophic indicator rankings for the 145 lakes are found in Table 19. A composite rank value was determined for each lake by pooling its four trophic indicator rank values and then once again ranking the 145 lakes (Table 20). In general, the rank positions are in good agreement with the 1977 qualitative and quantitative information. As always, however, these comparisons can only serve as a rough guide, since in making them it is assumed that the lakes have been stable from 1973, rather than dynamic, changing, and nonuniform, as is actually observed.

CLUSTER ANALYSIS

Cluster analysis ("numerical classification" in the words of Boesch 1977) was used to order the 145 Illinois water bodies into groups. Separate clusterings were accomplished using just the LANDSAT bands as attributes in sets of three (GRN, RED, IR1) and four (GRN, RED, IR1, IR2). Additional clusterings were made using, as attributes, the LANDSAT-estimated values for four trophic indicators (CHLA, SEC, TON, and TPHOS).

Spectral Classification of the Lakes

In this subsection, the results of the cluster analysis of raw MSS data are discussed. Natural lake groupings were established according to spectral characteristics from the four attributes (i.e., GRN, RED, IR1, and IR2 bands) for 145 Illinois water bodies. The objective of the classification process was to demonstrate general lake characteristics associated with user impairment. Interpretation of the dendrogram (Figure 58) established six distinct water groups of dissimilar spectral composition and intensity. The groups are comprised of water bodies having similar optical and physical characteristics. The clustering algorithm provides a nonbiased perspective of the spectral traits of the lakes. The spectral properties of each lake provide an integrated characterization of water quality and relate to water-use indices.

Cluster interpretation was accomplished by comparing the spectral composition and uniqueness of each cluster with water quality data, field evaluations, lake morphology, and watershed characteristics. The LANDSAT flyover during October of 1973 was supported by chemical, physical, and biological data collected by the NES sample program for 31 lakes. Since the classification procedure utilized spectral responses, the NES data were of limited value because many of the NES lake parameters have little or no direct impact on the lake spectra. Field surveys were made during the summer of 1977 for 72 of the MSS-sampled lakes. These surveys included physical, biological, and chemical information useful for comparison of lake clusters. Lake morphology, watershed information, and field evaluations of user impairments were available for most lakes to supplement the ground information base.

TABLE 19. RANKINGS OF 145 ILLINOIS LAKES BASED ON SET THREE MODELS AND ORDERED BY NAME

Lake Name	Serial Number	SEC	CHLA	TON	TPHOS	PC1Y5	PC1F5
Anderson	34	127	112	86	84	120	107
Apple Canyon	144	29	38	45	39	35	39
Argyle	157	40	3	5	22	5	7
Bakers	19	110	99	104	132	127	130
Bangs	56	32	66	35	16	38	26
Bath	166	108	11	70	109	85	96
Big	134	70	50	32	55	47	50
Big	176	117	68	57	74	87	74
Bracken	145	21	19	36	50	27	37
Calumet	18	142	96	88	119	125	122
Canton	36	73	22	10	25	25	21
Carbondale	38	134	131	82	127	100	111
Carlyle	14	79	30	4	3	19	8
Catherine	58	25	102	80	36	61	52
Cattail	125	86	69	127	134	109	127
Cedar	39	76	14	29	63	30	41
Cedar	55	30	85	73	34	51	44
Centralia	79	31	27	52	54	28	40
Chain	83	116	93	90	107	110	110
Channel	59	50	101	81	44	72	58
Charleston	16	121	103	94	95	112	108
Chautauqua	87	140	105	95	111	121	119
Clear	86	124	109	102	117	123	121
Coal City Recreation Club	138	10	18	3	11	3	3
Commonwealth Edison-Dresden Nuclear	137	92	52	14	15	41	25
Countryside	148	51	119	91	67	90	75
Crab Orchard	127	57	83	49	35	59	49
Crane	85	137	81	78	108	104	106
Crooked	149	65	125	115	125	136	132
Crystal	68	23	51	19	13	18	15
Decatur	73	111	124	105	75	114	101
Deep	150	9	63	30	7	33	18
DePue	3	130	120	118	118	126	125
Devil's Kitchen	128	6	36	47	33	16	27
Diamond	57	37	39	13	5	14	11
DuQuoin	98	67	136	140	124	130	131
Dutchman	49	11	20	39	52	23	36
East Loon	53	47	79	85	48	56	53
Fourth Lake	151	115	115	89	80	116	102

(continued)

TABLE 19. (continued)

Lake Name	Serial Number	SEC	CHLA	TON	TPHOS	PC1Y5	PC1F5
Fox	60	94	121	87	59	106	79
Fyre	170	53	87	120	93	93	98
Gages	152	28	84	54	24	48	34
George	108	18	6	12	18	11	12
Glen O. Jones	110	2	21	16	14	10	9
Goose	101	145	135	133	138	140	139
Goose (Village)	139	99	7	37	87	49	66
Grass	61	106	122	103	65	101	82
Greenville New City	2	80	123	101	76	98	89
Griswold	158	66	70	117	100	84	97
Harrisburg	111	55	67	99	78	64	69
Highland	153	35	116	100	43	79	60
Holiday	51	78	107	114	69	97	83
Horseshoe	1	85	92	132	135	122	133
Jack, Swan, Grass	165	123	127	121	112	131	126
Keithsburg	92	75	58	112	130	96	116
Kinkaid	40	1	2	1	1	2	1
Kinneman	168	101	26	44	104	65	78
Lake of Egypt	132	19	16	6	4	6	5
Lake of the Woods	115	109	37	113	131	118	128
Larue-Pine	121	107	141	143	145	143	143
Lily	136	135	49	72	123	92	104
Lincoln Trail	13	3	28	42	32	12	23
Little Grassy	119	5	43	38	20	21	20
Little Swan	185	89	40.5	21.5	56.5	42.5	45.5
Liverpool	88	119	8	60	113	80	91
Long	52	77	118	96	53	89	67
Long	177	131	73	69	105	94	100
Lower Smith	181	88	113	15	58	26	38
Lyerla-Autumnal	120	59	34	76	110	76	90
Marie	62	91	134	126	89	128	118
Marion	129	48	106	134	126	105	120
Marshall	81	114	140	108	121	113	117
Matanzas	89	138	91	84	91	108	103
Mattoon	24	62	31	11	19	24	17
McCullom	159	22	24	28	28	17	24
McGinnis	20	133	142	144	144	144	144
Meredosia	10	141	88	83	115	115	114
Mesa	184	16	13	20	17	15	16
Moscow	164	87	71	62	82	82	80
Moses	28	20	57	111	86	54	71
Mound	163	90	138	122	101	117	115

(continued)

TABLE 19. (continued)

Lake Name	Serial Number	SEC	CHLA	TON	TPHOS	PC1Y5	PC1F5
Murphysboro	37	14	25	43	41	13	30
New Pittsfield	100	129	45	31	66	62	59
Nippersink	63	102	126	106	70	111	94
Old Ben Mine	32	64	56	93	90	69	81
Olney East Fork	106	13	29	9	6	8	6
Olney New	107	39	32	74	81	46	61
Open Pond	174	74	60	119	133	103	123
Otter	167	60	23	53	79	44	57
Pana	113	49	4	8	31	7	10
Paradise	15	83	76	59	61	71	64
Paris Twin	25	42	55	109	92	57	76
Pekin	116	126	44	61	98	78	85
Petite	64	84	117	97	71	102	88
Pierce	130	52	90	66	51	60	56
Pinckneyville	99	72	97	79	62	91	68
Pistakee	65	68	95	71	42	70	54
Powerton Cooling	182	71	104	68	45	86	63
Quiver	90	100	54	41	64	55	55
Raccoon	80	104	62	25	40	63	51
Rend	29	63	53	24	12	32	19
Rice	35	103	133	125	97	132	124
Round	66	33	65	34	10	36	22
Saganashkee	21	96	139	135	122	134	134
Sahara Coal Company	175	118	1	48	114	68	84
Sam Dale	124	43	94	110	68	81	72
Sam Parr	41	41	64	128	129	83	109
Sand	147	15	82	51	23	45	33
Sanganois	9	122	77	56	102	77	86
Sara	26	4	15	26	29	9	13
Sawmill	103	144	143	142	142	142	142
Senachwine	104	143	137	124	103	138	129
Shelbyville	114	56	46	18	9	20	14
Skokie Lagoons	22	95	98	137	141	135	140
Slocum	54	98	145	145	143	145	145
Snyder's Hunting	142	69	59	123	116	67	95
South Wilmington	140	7	9	2	2	1	2
Spring	4	120	108	136	139	133	137
Spring	8	139	111	98	96	119	112
Spring	67	93	40.5	21.5	56.5	42.5	45.5
Spring	118	82	129	116	85	124	113
Spring Arbor	143	27	48	107	99	53	77
St Mary's	146	17	12	27	60	34	42

(continued)

TABLE 19. (continued)

Lake Name	Serial Number	SEC	CHLA	TON	TPHOS	PC1Y5	PC1F5
Stephen A. Forbes	78	26	47	50	37	37	35
Storey	50	44	89	33	47	40	43
Sugar Creek	178	125	114	55	106	74	87
Summerset	186	46	74	92	49	73	62
Sunfish	126	81	33	65	83	66	70
Swan	93	112	17	63	120	75	93
Swan	172	132	132	138	137	139	138
Tampier	23	61	35	64	77	52	65
Third	155	54	128	130	73	107	99
Thunderbird	173	8	5	7	8	4	4
Turner	102	136	130	141	140	141	141
Upper Smith	180	97	72	58	72	88	73
Vandalia	27	45	61	23	27	31	28
We-Ma-Tuk	33	58	10	17	46	22	32
West Frankfort New	31	34	78	75	38	50	47
West Frankfort Old	30	38	110	131	94	99	105
West Loon	156	12	80	46	21	39	31
Wolf	17	36	42	40	26	29	29
Wonder	69	105	144	139	128	137	136
Worley	117	113	86	129	136	129	135
Yorkey	179	128	75	67	88	95	92
Zurick	154	24	100	77	30	58	48

Cursory examination of the remote-sensing data indicated that the natural groupings of lakes developed by cluster analysis techniques discriminated groups of water bodies, each with its own unique physical qualities. Data for the four LANDSAT bands were rescaled in a manner suggested by Ruttner (1963). Thus, the raw reflectance values were transformed into percentages that were used as a four-element index of lake wavelength reflectance characteristics. The maximum and minimum reflectance values recorded for each band were assumed to represent a reasonable range to form the base index signatures. Establishing the range from actual energy return signals for water bodies minimized the path radiance interference from the base signal. Ground control data for suspensoids and Secchi depths verified this assumption.

This characterization of lake waters by their optical spectrum relies upon the relationships between the energy reflectance of the clearest Illinois lake and waters containing greater concentrations of suspended or dissolved matter. The procedure is similar to that used by Rogers (1977) except that no lake in the Illinois MSS program is considered an exceptionally pure-water lake. Hence, Illinois lake index signatures of reflectance data represent actual

TABLE 20. COMPOSITE RANKING OF 145 ILLINOIS WATER BODIES BASED ON SET THREE MODELS AND ORDERED BY INCREASING TROPHIC STATE

Lake Name	Serial Number	RANKSUM
Kinkaid	40	1
South Wilmington	140	2
Thunderbird	173	3
Coal City Recreation Club	138	4
Lake of Egypt	132	5
Glen O. Jones	110	6
George	108	7
Olney East Fork	106	8
Mesa	184	9
Argyle	157	10
Sara	26	11
Pana	113	12
Diamond	57	13
McCullom	159	14
Lincoln Trail	13	15
Crystal	68	17
Little Grassy	119	17
Deep	150	18
Carlyle	14	20
St Mary's	146	20
Dutchman	49	22
Devil's Kitchen	128	22
Mattoon	24	24
Murphysboro	37	24
Bracken	145	25
Shelbyville	114	26
Canton	36	27
We-Ma-Tuk	33	28
Round	66	29
Wolf	17	30
Bangs	56	31
Apple Canyon	144	32
Rend	29	33
Vandalia	27	34
West Loon	156	35
Stephen A. Forbes	78	36
Centralia	79	37
Sand	147	38
Commonwealth Edison-Dresden Nuclear	137	39
Cedar	39	40
Gages	152	41
Big	134	42
Little Swan	185	43
Spring	67	44
Storey	50	45
Otter	167	46
Cedar	55	47
Crab Orchard	127	48
West Frankfort New	31	49
Olney New	107	50
Goose (Village)	139	51
Raccoon	80	53
Zurick	154	53
Tampier	23	54
Catherine	58	55
East Loon	53	57
Quiver	90	57
Pierce	130	57
Summerset	186	59
Sunfish	126	60
New Pittsfield	100	61
Moses	28	63
Lower Smith	181	63
Kinneman	168	64
Channel	59	66
Pistakee	65	66
Paradise	15	68
Lyerla-Autumnal	120	68
Spring Arbor	143	70
Sahara Coal Company	75	70
Powerton Cooling	182	71
Highland	153	72
Paris Twin	25	74
Bath	166	74
Harrisburg	111	76
Upper Smith	180	76
Liverpool	88	77
Moscow	164	78
Old Ben Mine	32	79

(continued)

TABLE 20. (continued)

Lake Name	Serial Number	RANKSUM
Pinckneyville	99	80
Swan	93	81
Sam Dale	124	82
Big	176	83
Countryside	148	84
Pekin	116	85
Long	52	86
Griswold	158	88
Fyre	170	88
Sanganois	9	89
Yorkey	179	90
Fox	60	91
Sam Parr	41	92
Snyder's Hunting	142	93
Holiday	51	94
Petite	64	95
West Frankfort Old	30	96
Keithsburg	92	97
Long	177	98
Lily	136	99
Greenville New City	2	100
Third	155	101
Open Pond	174	102
Lake of the Woods	115	103
Grass	61	104
Fourth Lake	151	105
Sugar Creek	178	106
Nippersink	63	108
Crane	85	108
Matanzas	89	108
Chain	83	110
Anderson	34	111
Spring	118	112
Charleston	16	113
Marion	129	114
Decatur	73	115
Cattail	125	116
Meredosia	10	117
Crooked	149	118
Marie	62	119
Horseshoe	1	121
Spring	8	121
Calumet	18	123
Bakers	19	123
Chautauqua	87	125
Mound	163	125
Clear	86	126
Rice	35	127
Worley	117	128
DuQuoin	98	129
Skokie Lagoons	22	130
Carbondale	38	131
Marshall	81	132
Jack, Swan, Grass	165	133
DePue	3	134
Saganashkee	21	135
Spring	4	136
Senachwine	104	137
Wonder	69	138
Slocum	54	139
Larue-Pine	121	140
Swan	172	141
Turner	102	142
Goose	101	143
McGinnis	20	144
Sawmill	103	145

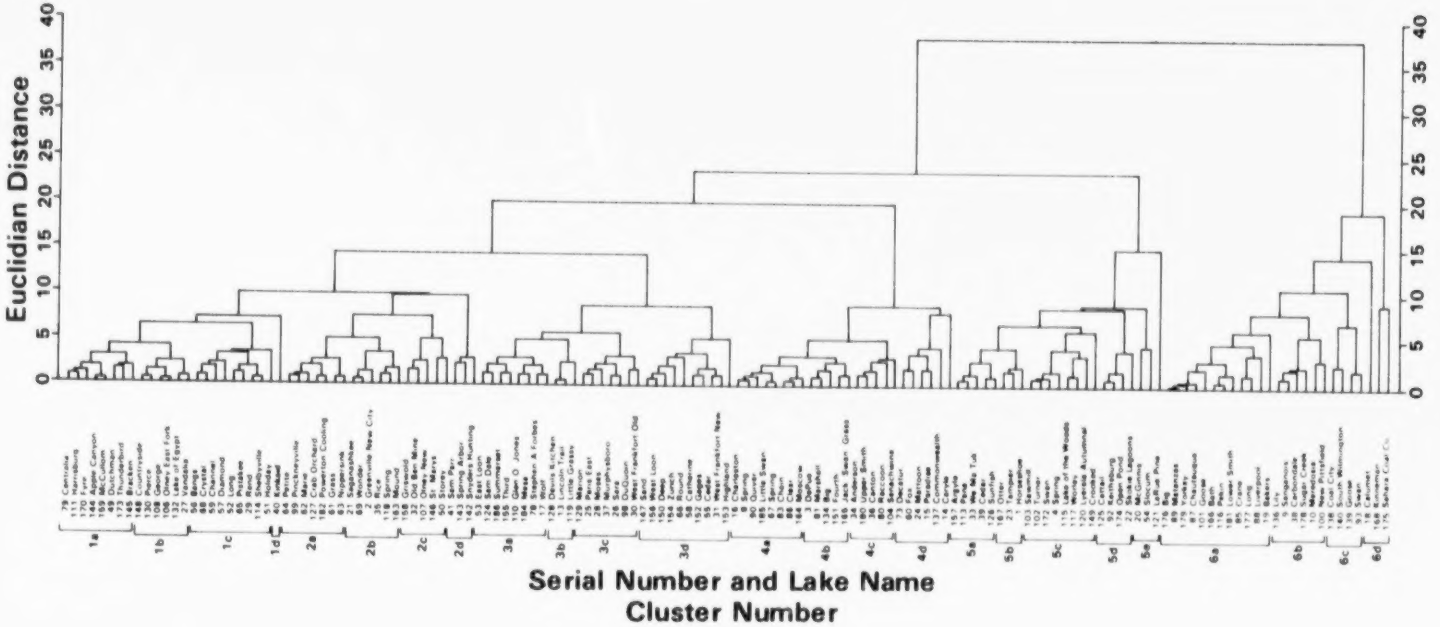


Figure 58. Dendrogram of 145 Illinois water bodies based on complete linkage clustering on four spectral attributes (GRN, RED, IR1, IR2). The dissimilarity axis is in the distance scale Δ. The attributes' values were not standardized prior to computing the Δ^2 values for the resemblance matrix.

optical qualities for these lakes and are not a comparison of these lakes to "pure-water lakes" found elsewhere.

Generalized signatures for various types of Illinois water bodies are found in Table 21. These signatures represent actual reflectance differences in the LANDSAT MSS bands for lake waters integrated over Secchi depth. Since most Illinois lakes exhibit a Secchi depth of less than one meter, and because most solar radiation is absorbed within one meter (Ruttner 1963), the procedure provides a reasonable demonstration of Illinois lake properties. Use of the actual range of recorded spectral values to establish index signatures provides an objective and comparable data base to establish a "real world" interpretation of Illinois lake groups.

Cluster analysis resulted in the delineation of 6 groups of 21 to 28 lakes each, arranged in distinct subgroups (Figures 58 and 59). Index signatures and general lake qualities for the six clusters are in shown Table 22.

Some semiquantitative characteristics of the lake clusters and their subclusters at level six are readily apparent when compared to the ground control data in Table 23. The six clusters can be ordered on the basis of declining water quality as follows: 3-1-2-5-4-6. Based upon this order, Figure 60 demonstrates the correlation between spectral signatures and 1977 Secchi depth and suspensoid levels for 72 of the 145 lakes. Suspensoid contact-sensed data are available for 1977 for each subcluster of clusters 1 to 6 and represent 42 to 82 percent of the lakes in each group. The obvious relationship between Secchi depth and proportionate concentrations of volatile (organic) and total suspended solids suggest that the lake clusters can be discriminated by Secchi depths, total suspended matter, and the proportions of inorganic-organic suspensions.

Clusters 3 and 1 have similar organic suspensoid levels but are separable by their inorganic suspensoid levels and associated changes in Secchi depths. Clusters 5 and 4 demonstrate a similar pattern indicating that inorganic turbidities account for the differences between Clusters 3 and 1 and also for those between 5 and 4. Cluster 2 represents lakes exhibiting qualities between these two sets. Algal concentrations for the 72 lakes sampled during 1977 closely follow the volatile suspended solids values indicating that primary productivity increases from Cluster 3 to 5 and then decreases in Cluster 4. The abrupt reduction in algal counts from Cluster 5 to 4 corresponds with a 100 percent increase in inorganic suspensions and a Secchi depth reduction of 50 percent (to 0.28 m) in Cluster 4. Cluster 6 appears to follow the ordered relationship according to actual spectral information; contact-sensed data to demonstrate suspensoid levels and Secchi depth relationships for this cluster are available for only four lakes. Generally, lakes in Cluster 6 are considered poor quality lakes that were either privately owned lakes or were too shallow to sample during the 1977 survey.

Figure 61 suggests that the 1973 NES data and the 1977 IEPA data for Secchi depth qualitatively corresponds with the LANDSAT RED band. Figure 62 demonstrates the correspondence of suspensoid levels and light extinction properties of Illinois lakes during 1977. The relationship between suspensoids, Secchi depth, and spectral response is obvious. Generally, the

TABLE 21. INDEX SIGNATURES FOR VARIOUS WATER BODY TYPES IN ILLINOIS

Type of Water Body	LANDSAT MSS Band Percentages GRN	RED	IR1	IR2
Clean glacial lakes	5	10	5	5
Clear deep reservoirs	5	5	15	25
Low algal clear reservoirs	20	20	15	10
High algal reservoirs	30	30	25	10
High algal glacial lakes	25	25	20	5
Turbid reservoirs	40	45	30	25
River backwaters	55	55	50	30
Sloughs and harbors	85	90	90	90

TABLE 22. INDEX SIGNATURES AND GENERAL DESCRIPTIONS FOR SIX ILLINOIS LAKE CLUSTERS

Cluster Number	Signature GRN-RED-IR1-IR2	Cluster Description
3	10-10-15-16	Deep clear lakes of excellent quality with macrophytes
1	25-22-22-19	Deep somewhat clear lakes of good to very good quality with slight sediment, algal, and macrophyte problems
2	27-29-33-23	Moderate depth lakes of good quality with moderate silt and algal problems, slight macrophyte problems, and average Secchi depths
5	40-42-54-41	Shallow reservoirs and backwaters of fair quality with moderate sediment problems and severe algal problems
4	49-53-41-21	Shallow lakes and backwaters of poor quality with low Secchi depths and severe sediment-related problems
6	67-68-62-44	Shallow lakes and backwaters of very poor quality with sediment-related turbidity problems

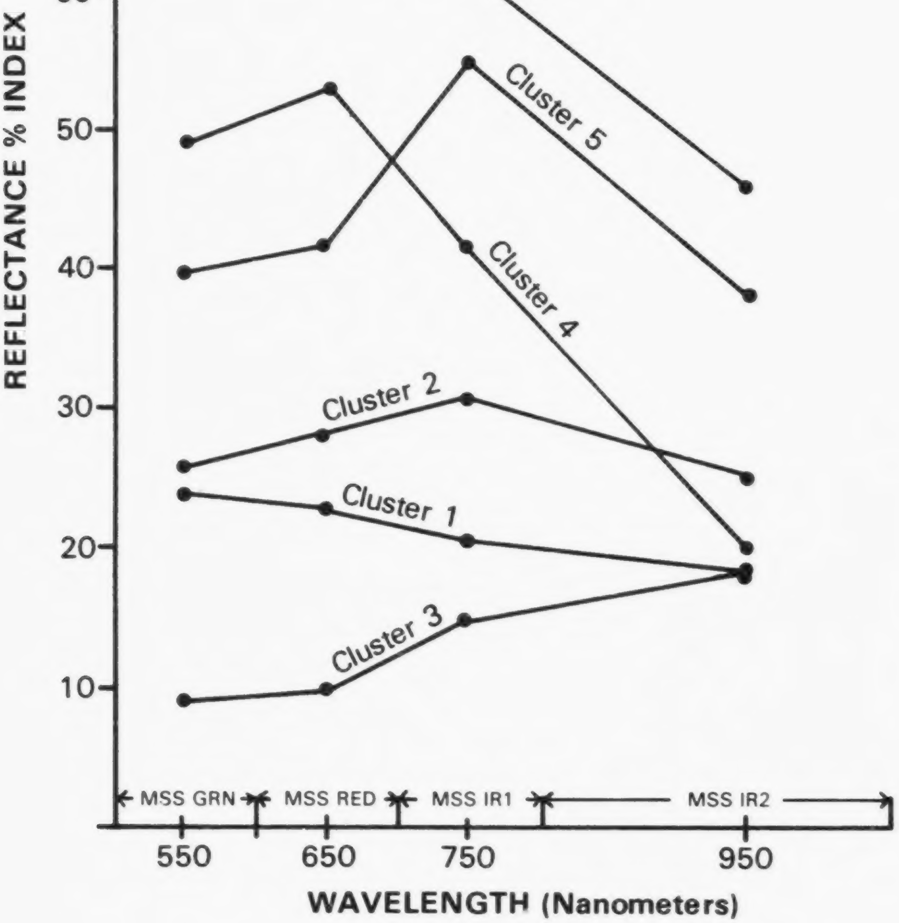


Figure 59. Spectral index signature curves for six lake clusters based upon raw MSS data.

TABLE 23. SPECTRAL DATA AND CONTACT-SENSED DATA FOR THE CLUSTERS AND SUBCLUSTERS DEVELOPED USING COMPLETE LINKAGE CLUSTERING ON FOUR ATTRIBUTES (GRN, RED, IR1, IR2)*

Cluster Number and (Obs.)	Scaled Spectral Signature				IEPA Data (1977)			Observed Problems			NES Data (1973)		Morphology		Hydrology				Biota
	GRN	RED	IR1	IR2	TSS	VSS	SEC	Sediment	Algae	Macrophyte	SEC	CHLA	$\bar{Z}$	Z_m	Watershed Equivalent Centimeters	Detention Time	Volume loss Related to Sedimentation	1973 Flush by Rain Runoff	1977 Algal Enumeration
3d (10)	11	9	6	5	6.4	5.4	1.32	1.3	2.0	2.7	2.77	6	3.72	11.19	90.9	4.20	0.13	9.7	0.6
b (3)	6	2	13	33	1.3	1.0	3.31	1.0	1.3	1.7			7.53	21.23	61.2	1.81	0.09	6.2	0.4
a (8)	13	13	18	17	8.8	6.4	1.14	1.6	2.4	2.7	0.91	27	3.84	9.85	39.4	1.46	0.40	9.2	2.8
c (7)	5	11	25	30	8.7	6.9	0.95	2.0	2.6	2.7			3.57	8.90	22.1	0.71	0.30	32.0	5.2
3 (28)	10	10	15	16	7.0	5.9	1.43	1.5	2.2	2.6	1.83	17	4.12	11.46	53.8	2.25	0.32	18.9	2.3
1b (6)	29	23	24	21	6.6	4.4	1.40	2.0	2.0	2.4	0.70	13	4.57	11.95	33.0	1.30	0.18	9.0	1.2
c (9)	21	22	17	10	10.3	9.0	1.13	2.0	2.4	1.8	0.43	39	3.63	10.33	43.4	2.09	0.11	57.6	1.4
a (8)	22	19	27	29	9.3	3.7	1.04	1.9	1.9	2.7			4.63	11.16	25.9	1.00	0.20	11.7	6.9
d (1)	50	19	17	15	1.0	0.0	1.97	1.0	1.0	2.0			8.75	24.38	56.9	1.72	0.04	6.7	0.3
1 (24)	25	22	22	19	9.7	5.8	1.27	1.9	2.1	2.3	0.49	33	4.42	11.58	34.8	1.46	0.16	29.7	2.5
2d (3)	11	17	35	46	3.0	2.0	1.65	2.0	2.5	3.0			2.65	8.23	31.2	0.97	0.24	13.6	13.0
a (7)	29	32	26	10	14.5	9.0	1.51	2.6	2.7	1.9	0.40	54	2.23	6.22	18.8	0.57	0.14	23.7	5.3
c (5)	29	26	37	34	15.3	10.6	0.70	2.5	2.5	3.0	0.49	24	2.80	5.73	23.4	0.94	0.07	13.6	3.2
b (6)	30	34	35	19	39.3	18.3	0.39	2.6	2.4	1.8	0.46	198	2.23	5.06	19.8	0.95	0.13	23.0	9.5
2 (21)	27	29	33	23	21.8	11.9	0.88	2.5	2.6	2.3	0.43	77	2.44	6.10	23.1	0.90	0.14	25.4	7.7
5a (5)	42	46	41	36	13.7	8.7	1.37	2.2	2.2	1.8			4.60	8.96	13.5	0.54	1.17	272.0	4.9
b (3)	34	38	46	37	27.0	16.0	0.33	2.3	2.5	2.3	0.18	182	1.07	2.59	16.0	0.78	0.28	40.0	11.3
e (3)	31	27	72	52	25.0	21.0	0.34	2.3	3.7	3.0	0.31	241	0.76	1.95	6.9	0.34	0.59	61.5	30.5
c (8)	44	47	55	32	31.0	16.0	0.30	3.3	2.0	1.7			1.49	3.60	30.0	1.07	0.12	19.2	2.9
d (4)	38	41	58	61	65.0	40.0	0.14	3.3	3.0	2.0			0.61	1.74					7.4
5 (23)	40	42	54	41	31.7	21.5	0.59	2.7	2.5	2.0	0.24	212	1.83	4.30	13.2	0.69	0.72	143.2	11.4

(continued)

TABLE 23. (continued)

Cluster Number and (Obs.)	Scaled Spectral Signature				IEPA Data (1977)			Observed Problems			NES Data (1973)		Morphology		Hydrology				Biota
	GRN	RED	IR1	IR2	TSS	VSS	SEC	Sediment	Algae	Macrophyte	SEC	CHLA	$\overline{Z}$	Z_m	Watershed Equivalent Centimeters	Detention Time	Volume loss Related to Sedimentation	1973 Flush by Rain Runoff	1977 Algal Enumeration
4c (5)	56	56	43	18	57.3	22.5	0.39	3.0	2.4	1.8	0.43	10	1.62	3.87	19.6	0.88	0.32	97.9	19.3
d (6)	44	47	34	11	29.0	9.0	0.34	3.0	2.0	1.4	0.43	33	2.44	7.83	3.8	0.16	1.52	53.9	4.1
a (8)	51	56	48	27	77.8	31.8	0.30	3.4	2.0	1.4	0.24	18	1.43	5.12	5.8	0.27	3.07	724.8	2.1
b (5)	46	51	49	24	120.0	27.0	0.11	3.3	1.7	1.7	0.15	58	0.82	1.62	45.0	2.22	0.12	5.6	1.0
4 (24)	49	53	41	21	61.8	22.6	0.28	3.2	2.1	1.6	0.37	31	1.68	4.94	11.7	0.61	1.49	233.7	6.6
6a (12)	59	62	57	33	68.0	20.0	0.11	3.2	1.5	1.5			0.88	2.35	23.1	1.14	0.15	11.0	
b (4)	70	77	68	39	150.0	39.0	0.11	3.2	2.2	1.2			2.04	5.12	15.0	0.53	0.25	26.1	55.1
c (6)	71	56	54	62				2.5	1.3	1.3			8.14	18.59	0.3				
d (3)	91	88	80	69				4.0	1.0	1.0			2.44	3.05					
6 (25)	67	68	62	44	58.0	16.8	0.11	3.1	1.6	1.4			2.35	5.49	13.2	0.56	0.22	20.7	

*Parameter means were constructed for 6 clusters and 25 subclusters. Parameters, acronyms, and units are as follows:

Scaled spectral signature - LANDSAT bands were scaled (0-100) using approach described in text.

IEPA Data (1977) - Data collected by Illinois Environmental Protection Agency during summer of 1977. TSS - total suspended solids (mg/liter). VSS - volatile suspended solids (mg/liter). SEC - Secchi depth (m).

Observed Problems - Problems noted through field observations and adversely affecting use. Scaled 0-4 with 0=minimal problem and 4=severe problem.

NES Data (1973) - Data collected by U.S. EPA's National Eutrophication Survey in October 1973. SEC - (m). CHLA - (μg/liter)

Morphology - Data from IEPA files. $\overline{Z}$ - mean depth (m). Z_m - maximum depth (m).

Hydrology - Data from IEPA files. Watershed equivalent centimeters - reservoir volume divided by watershed area (cm^3/cm^2). Detention time (years). Volume loss related to sedimentation - annual loss of lake volume expressed as a percentage. 1973 flush by rain runoff - percent of lake volume replaced by runoff from heavy rains just prior to dates of LANDSAT coverage.

Biota - Data from IEPA files. 1977 algal enumeration (cells x 1000/ml).

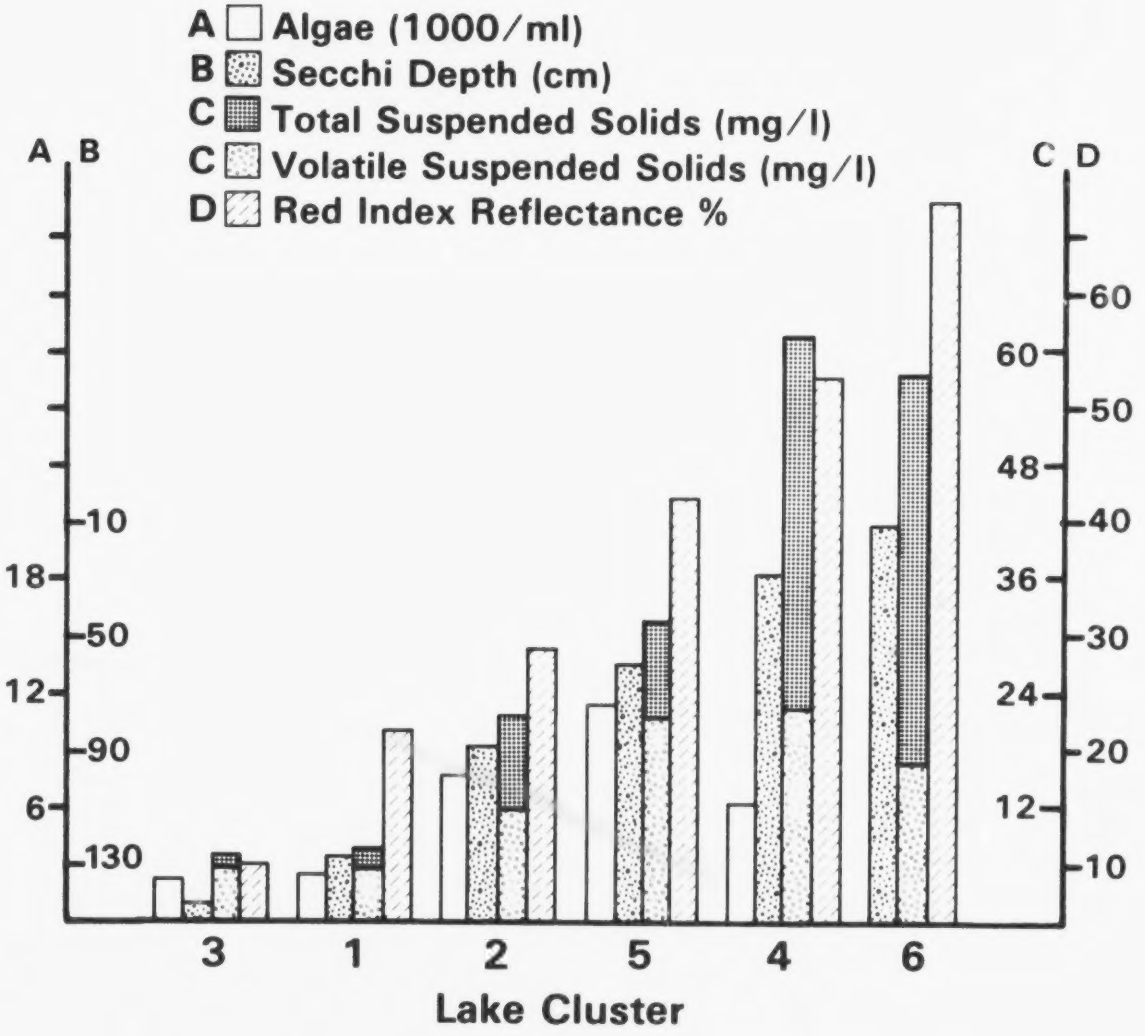


Figure 60. Visual correlation between contact-sensed data and scaled MSS RED band data at the six-cluster levels. The parameter values are cluster means from the 1977 contact-sensed data.

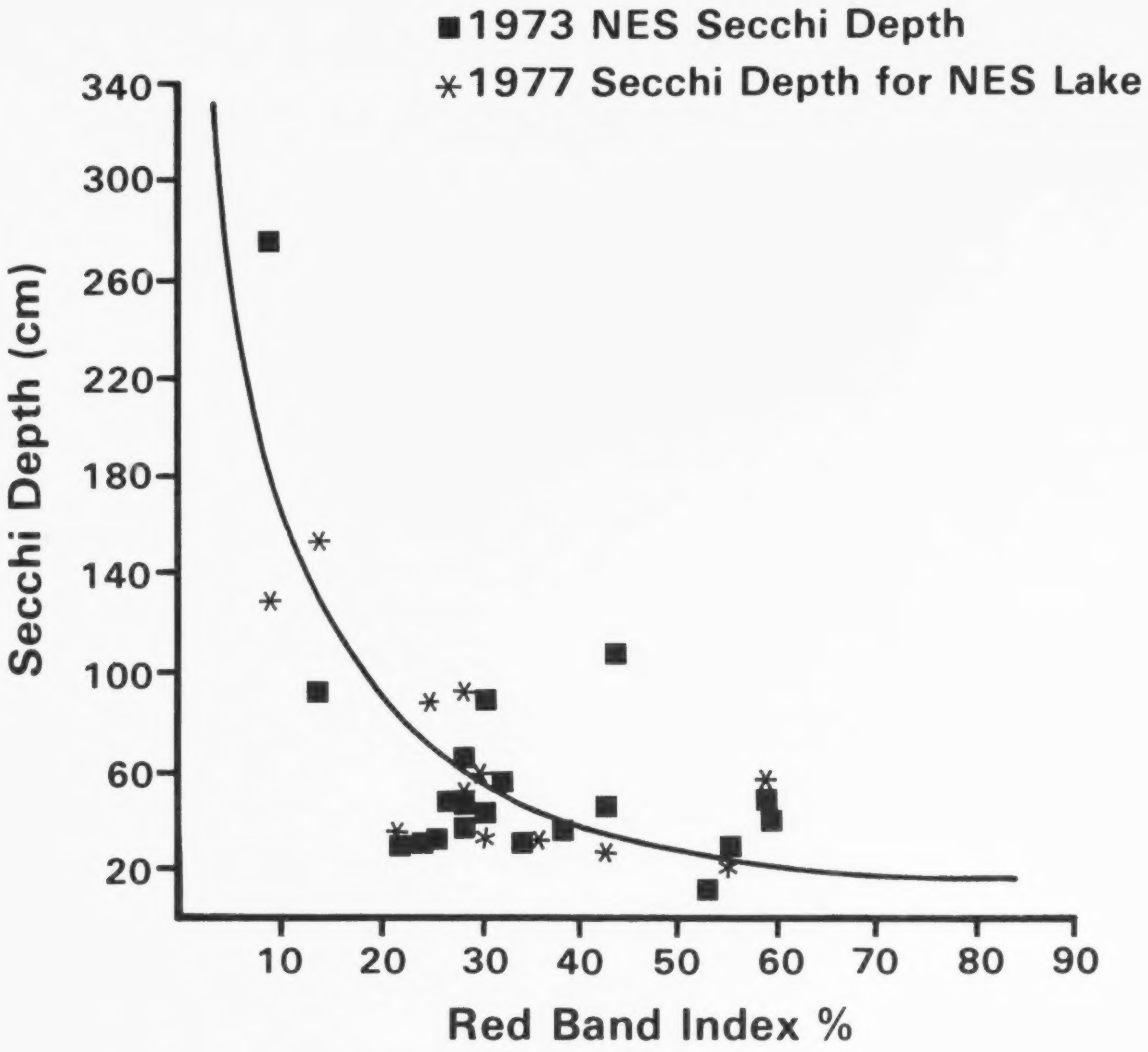


Figure 61. Light extinction relationship between MSS RED band index (percent) and Secchi depth measurements taken in 1977. The line is a trend line obtained by a visual fit, not a regression.

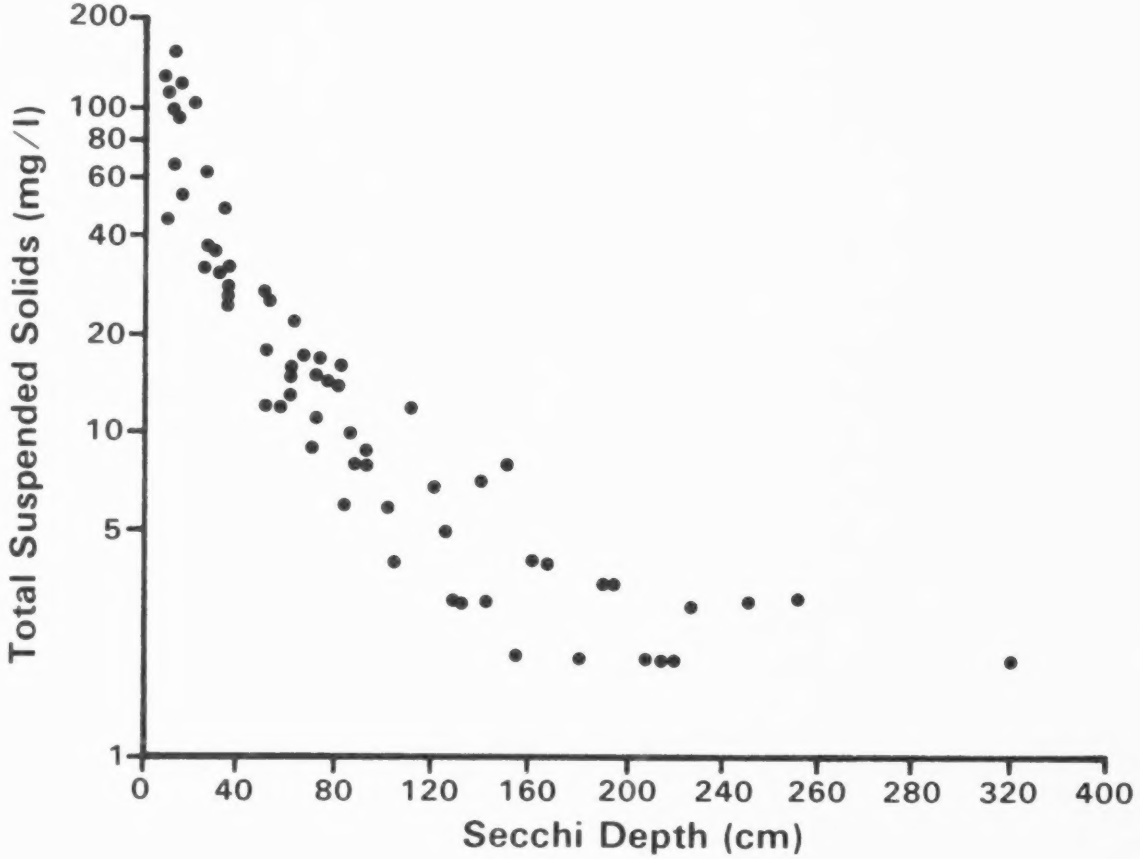


Figure 62. Total suspended solids relationship with Secchi depth. Data are mean values for each lake sampled during 1977.

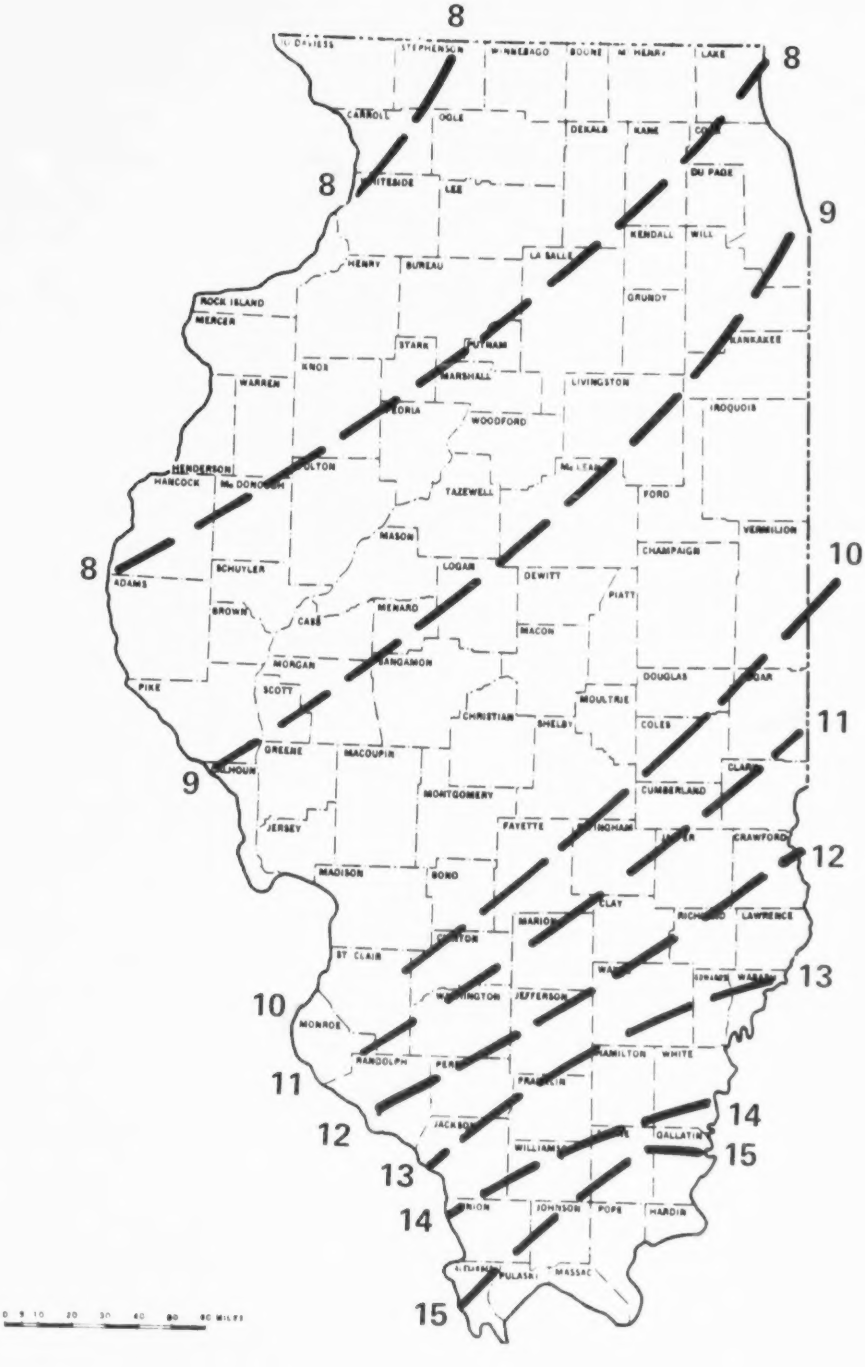
spectral reflectance values increase in cluster order 3-1-2-5-4-6 as shown in Figure 59 and Table 23. Corresponding increases in total and volatile suspended solids follow a similar pattern, while Secchi depths demonstrate a progressive decrease in light penetration (Figure 60, Table 23). Algal data for 1977 correlate with the general pattern found in the field observations of use impairment and correspond to Secchi and volatile suspended solids data. Similar trends for Secchi depths and chlorophyll a concentrations are evident in the 1973 NES data, the extensive ground control data of 1977, the use impairment evaluations, and the spectral index signatures.

Chlorophyll a levels and algal counts indicate primary productivity increases from deep lakes to shallow water bodies until the inorganic suspensoids decrease Secchi depths below one-half meter. The most turbid water bodies are encountered in Clusters 4 and 6. These trends suggest that user impairment is related to lake morphology and suspensoids. Algal suspensoids selectively affect shallower water bodies unless sediment-related turbidities are excessive. Suspended sediment appears to progressively impact use impairment as water bodies become shallower and ultimately becomes the single factor determining loss-of-use potential in the worst lakes. Macrophyte use impairment is most significant in deep, clear waters and gradually becomes less conspicuous as suspensoids increase and Secchi depths decrease.

Thus, suspensoids are a significant factor in determining Illinois lake qualities and impairments. Table 23 summarizes lake morphology and hydrological information for lake clusters and subclusters to demonstrate the obvious relationship of lake morphology to the use impairment factors discussed above. The decrease in mean and maximum depths generally follow the established lake cluster order (Table 23) as do the volatile and total suspended solids relationships. Clusters 3 and 1 are deep, clear water bodies with well-developed basins, while Clusters 5 and 4 consist of shallow turbid lakes. Cluster 2 is between these.

Interpolation of hydrological data for these clusters provides insight as to their behavior regarding suspensoid levels and Secchi depths. Analysis of the equivalent flushing rate and normal detention time of lakes indicates that the concentration of inorganic suspensoids is a function of inputs from runoff. Calculations for detention times account for the average annual runoff values (Figure 63) expected for each watershed. The detention period for lake clusters decreases in the order 3-1-2-5-4-6, corresponding to the inorganic suspensoid and MSS reflectance index signature increases in the same order. This inverse relationship of detention time to lake quality can be interpreted as a direct correlation of lake flushing to suspensoid levels and overall qualities. Therefore, it follows that shallow reservoirs with large watersheds will be more severely impaired than deep reservoirs with long detention capacity.

Illinois lakes are significantly influenced by their flushing rates. Short-detention lakes are of poorer quality, irrespective of appreciable nutrient inputs, than are lakes with long hydraulic retention times. Therefore, light inhibition may be more significant in determining Illinois lake impairment than the classical nutrient trophic index procedures. It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0 5 10 20 30 40 50 60 MILES
STEPHENSON
WINNEBAGO
BOONE
McHENRY
LAKE
CARROLL
OGLE
DEKALB
KANE
COOK
DU PAGE
WHITESIDE
LEE
KENDALL
WILL
HENRY
BUREAU
LA SALLE
GRUNDY
ROCK ISLAND
MERCER
STARK
PUTNAM
KANKAKEE
KNOX
MARSHALL
LIVINGSTON
WARREN
PEORIA
WOODFORD
IROQUOIS
HENDERSON
HANCOCK
McDONOUGH
FULTON
TAZEWELL
McLEAN
FORD
MASON
VERMILION
ADAMS
SCHUYLER
LOGAN
DEWITT
CHAMPAIGN
BROWN
CASS
MENARD
PIATT
MACON
MORGAN
SANGAMON
DOUGLAS
PIKE
SCOTT
MOULTRIE
EDGAR
CHRISTIAN
SHELBY
COLES
GREENE
MACOUPIN
CALHOUN
CLARK
MONTGOMERY
CUMBERLAND
JERSEY
FAYETTE
EFFINGHAM
JASPER
CRAWFORD
MADISON
BOND
CLAY
MARION
RICHLAND
LAWRENCE
CLINTON
ST CLAIR
WAYNE
WABASH
WASHINGTON
JEFFERSON
MONROE
RANDOLPH
PERRY
FRANKLIN
HAMILTON
WHITE
JACKSON
WILLIAMSON
SALINE
GALLATIN
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC

Figure 63. Average annual runoff for Illinois in inches/square mile/year (Upper Mississippi River Basin Study Commission 1970).

appears that algal productivity is proportionate to flushing rates until the inorganic suspensions mask the effects of nutrient flushing by restriction of the euphotic zone. Obvious relationships of lake morphology and watershed hydraulics to the overall quality of Illinois lakes are summarized in Table 23.

To further examine the relationships between lake quality characteristics and lake morphology and hydraulic characteristics, equivalent flushing rates were determined for the clusters from meteorlogical conditions just prior to satellite flyover (Figure 64 and Table 23). The equivalent flush occurring just prior to the MSS sampling in 1973 does not account for the good-to-excellent quality water bodies of Clusters 3, 1, and 2 since those were not flushed by significant amounts of runoff prior to sampling. Clusters 4 and 5, on the other hand, were flushed by significant amounts of runoff and are comprised of lakes with poor water quality. The general flushing trend increases in cluster order 3-1-2-5-4-6 and corresponds to higher suspensoid loads than expected for annual watershed equivalent centimeter volumes and detention times. The rainfall amounts that occurred during October, 1973, were not unusual for this time of year.

Volume loss estimates given in Table 23 relate to morphology and hydrology of the lake and its watershed. Watershed physiography, geology, and soil types affect the sediment impact. Discussion of these factors and their bearing on the lake clusters is given in the detailed lake cluster descriptions. Volume loss from sedimentation can be misleading because this figure represents a percent loss by lake volume and not a concentration in the water column. In addition, lakes having larger watersheds generally have proportionally lower sedimentation losses because less sediment reaches the reservoir. Sediment-trap efficiency decreases as the reservoir capacity decreases, and consequently an increased amount of sediment is passed through the reservoir outlet. Thus, long-detention lakes may have greater trap efficiency and higher volume losses than short-detention lakes, even though their loadings are similar.

Lake Cluster Characteristics--

Table 23 lists representative data for the lake clusters. In addition, values for subclusters were included to indicate the variability of lake types within a cluster. Appendix A-5 gives individual data for each lake within the clusters and subclusters. The lake classification developed by this effort generally is based upon the physical properties and characteristics of lakes. This approach provides an objective comparison of the water transparency as it is affected by weed growth, nuisance algal blooms, impaired water quality, sediment infilling, and turbidity. These problems are directly related to impairment of use and do not consider the nutrient budgets as a means to characterize lakes in Illinois.

The following discussion provides a characterization of the lake clusters established by spectral responses. The agreement of ground truth information, subjective observations of lake problems, watershed characteristics, and lake morphology suggest the approach is valid. Watershed geology and soil associations are included in the analysis.

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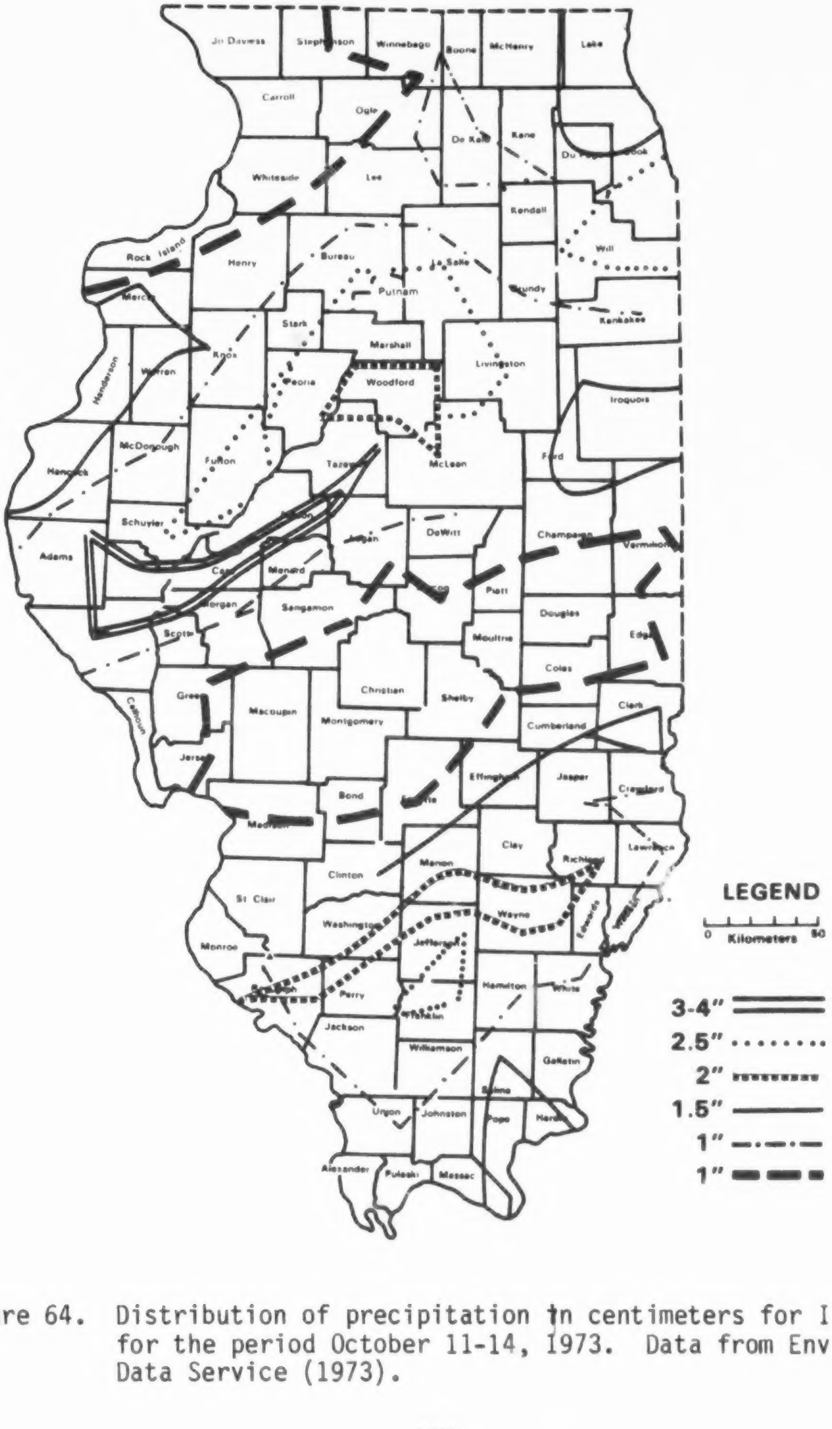
Jo Daviess
Winnebago
Boone
McHenry
Lake
Carroll
Ogle
De Kalb
Kane
Cook
Whiteside
Lee
Kendall
Rock Island
Henry
Bureau
La Salle
Will
Putnam
Grundy
Mercer
Stark
Kankakee
Knox
Marshall
Henderson
Warren
Peoria
Woodford
Livingston
Iroquois
McDonough
Fulton
Tazewell
McLean
Ford
Hancock
Schuyler
DeWitt
Champaign
Adams
Vermilion
Menard
Piatt
Morgan
Sangamon
Douglas
Scott
Moultrie
Edgar
Coles
Christian
Shelby
Clark
Macoupin
Montgomery
Cumberland
Calhoun
Jersey
Jasper
Crawford
Bond
Madison
Clay
Lawrence
Clinton
Marion
Richland
St Clair
Wayne
Washington
Edwards
Monroe
Jefferson
Perry
Hamilton
White
Jackson
Franklin
Williamson
Gallatin
Saline
Union
Johnston
Pope
Hardin
Alexander
Pulaski
Massac
LEGEND
0 Kilometers 50
3-4"
2.5"
2"
1.5"
1"
1"

Figure 64. Distribution of precipitation in centimeters for Illinois for the period October 11-14, 1973. Data from Environmental Data Service (1973).

Cluster 3 characteristics--This cluster generally represents lakes in Illinois having excellent characteristics and associated trophic qualities. The average depth of visibility (Secchi depth) is 1.43 m. Volatile suspended solids comprise over 80 percent of the total suspensoids by weight, indicating that most of the light-extinction properties are of organic origin. The TSS values are the lowest recorded for all lakes.

Field evaluations of lake conditions demonstrated that sediment-related turbidities are minimal. Some problems occur as a result of algal blooms. Macrophyte growths are moderate and may be associated with the relatively clear waters in these lakes.

The cluster includes most of the good quality, natural glacial lakes of less than 100 surface hectares in the Great Lakes section of the Central Lowland province (Figure 2). Most other lakes in this cluster are small-to medium-size south-central or southern Illinois impoundments in the Tills Plains section and are associated with weathered Illinoian glacial drift deposits (Figure 2). Their watershed soils are generally low in productivity, with less than one percent organic matter, and are light-colored with high clay content.

Cluster 3 lakes are generally deep (for Illinois) and well developed, with the mean depth for the group averaging 4.12 m and the maximum depth averaging 11.46 m. The average lake volume, expressed as watershed equivalent centimeters (reservoir volume divided by drainage basin area (cm^3/cm^2)), is over 53.8. This high value represents lakes having average detention periods of 2.25 years, generally ranging between 0.5 and 9 years. Rainfall prior to satellite flyover was equivalent to an average volume displacement of 19 percent for all lakes in this group. This value represents the lowest equivalent displacement of all clusters. The watersheds generally have less than 1.25 m of loess deposits. The long detention periods and watershed soil types result in an estimated annual lake capacity loss from sediments of 0.32 percent.

Cluster 1 characteristics--This cluster represents lakes of good quality associated with moderate sediment, algal, and macrophyte problems. The average Secchi depth is slightly less than Cluster 3 lakes, although the organic suspensoids remain constant. The moderate increase in total suspended solids, when compared to Cluster 3 lakes, indicates increased inorganic turbidities and losses of light penetration. Field observations suggest that the more sparse macrophyte growths are primarily the result of increased sediment-related turbidity levels in this group.

This group of lakes has a mean depth averaging 4.42 m and a maximum depth averaging 11.58 m. Although their morphology is similar to Cluster 3 lakes, this group has larger watersheds. The average lake volume, expressed as watershed equivalent centimeters, is less than 34.8. The average lake detention period is 1.46 years and generally is from 0.3 to 6 years. Rainfall prior to satellite flyover represented an average volume displacement of nearly 30 percent, a significant increase over Cluster 3 lakes. Annual average lake capacity loss from sediment is estimated to be approximately 0.16 percent.

Most of these lakes have watersheds in glacial drift generally associated with loess deposits of less than 1.25 m. All lakes are either natural glacial lakes, gravel pits, or artificial reservoirs. The reservoirs vary from 19 to 2,953 ha and generally are associated with Illinoian glacial drift of the Till Plain section. In general, sediment, algae, and macrophyte problems are slight to moderate.

Cluster 2 characteristics--Cluster 2 lakes are similar to Cluster 3 and 1 lakes except that their water quality is lower. Moderate turbidity and algae bloom problems occur. Macrophyte abundances are not excessive, a consequence of the turbidity conditions. These lakes have almost twice the concentrations of both total and volatile suspended solids and are associated with a 40-percent decrease in the depth of visibility when compared to Cluster 3 lakes. Sediment-related turbidity problems appear to contribute to the Secchi depth average of less than one meter. The NES chlorophyll a values suggest that algal problems are progressively worse from Cluster 3 to 1 to 2; changes in volatile suspended solids values for these clusters qualitatively correspond to changes in chlorophyll values.

This group of lakes has a mean depth averaging 2.4 m and a maximum depth averaging 6.1 m. The average lake volume, expressed as watershed equivalent centimeters, is about 23. The detention period ranges from 0.4 to 2 years and averages 0.9 years. Thus, these lakes have significantly shorter detention times than the previous clusters. Rainfall prior to satellite flyover represented an average volume displacement of about 25 percent. Although this average displacement value is less than the Cluster 1 value, the individual lake values in Cluster 2 lakes varied less.

Lakes in Cluster 2 include natural glacial flowage lakes known to be turbid and productive, shallow natural glacial lakes, several river backwaters, and artificial reservoirs. Most of the reservoirs have watersheds associated with Illinoian glacial drift with loess deposits having light-colored soils with less than 1 percent organic matter. Average annual lake capacity loss from sediment is estimated at 0.14 percent.

Cluster 5 characteristics--This cluster represents lakes having moderate to severe sediment-related turbidities and algal blooms and moderate macrophyte growths. In general, inorganic and organic suspensoids are high. The volatile suspensoids account for nearly two-thirds of the total suspensoids, which are nearly four times those found in the best quality lakes (Cluster 3). Secchi depth averages about 0.6 m, as compared to 1.4 and 0.9 m for Clusters 3 and 2, respectively.

This group of lakes has a mean depth averaging 1.8 m and a maximum depth averaging 4.3 m. It includes natural backwater lakes in the bottom lands with alluvium and no loess deposits, as well as sloughs and artificial reservoirs. The reservoirs have an average lake volume of about 13, expressed in watershed equivalent centimeters. Detention periods generally range from .007 to 2 years and average 0.69 years. Rainfall prior to satellite flyover represented an average volume displacement of about 143 percent. This value represents a significant displacement for reservoirs.

Ground samples during 1977 indicated that the deeper reservoirs are generally clear waters except after high runoff periods. The average annual lake capacity loss from sediments is estimated to be 0.72 percent. The backwater areas receive overflows from the adjacent rivers and have turbid waters of poor to fair quality. Reservoirs deeper than 4 m are considered to be fair to good quality lakes, while the shallower reservoirs are generally of poor quality.

Cluster 4 characteristics--This cluster represents lakes having severe sediment-related turbidities, moderate algal bloom problems, and minimal macrophyte problems. Secchi depth is less than 0.3 m, or less than one-half the depth observed in Cluster 5 lakes. The total suspended solids of Cluster 4 lakes is double the average for Cluster 5, although the volatile suspensoids are at about the same level. The significant decrease in depth of visibility corresponds with the increase in sediment.

This group of lakes has a mean depth averaging 2.4 m and a maximum depth averaging 4.9 m. Most of the artificial reservoirs drain watersheds of Wisconsin glacial drift with less than 1.25 m of loess deposits. Their soils are dark-colored and productive and have more than 1 percent organic matter. The average lake volume, expressed in watershed equivalent centimeters, is only 5.8. The detention period ranges from 0.002 to 0.546 years. Rainfall prior to satellite flyover represented an average volume displacement of nearly 360 percent. The annual lake capacity loss from sediment ranges between 0.06 and 8.5 percent and averages about 1.8 percent. The quality of the reservoirs is considered fair, while the natural backwaters are in poor condition. These lakes do not have excessive macrophyte growth problems. Field observations suggest this is primarily because of the sediment-related turbidity.

Cluster 6 characteristics--Cluster 6 lakes are generally of poor quality, with severe sediment-related turbidity problems. The group is composed of many shallow-river backwater lakes as well as harbors or artificial reservoirs experiencing significant sedimentation problems. Contact-sensed data are limited to four lakes. Two reservoirs sampled in 1977 had low suspensoids loads and good Secchi depth readings but are known to have experienced severe suspended solids problems in the past. Both watersheds have more than 1.25 m of loess deposits. The two backwater lakes sampled during 1977 exhibited extremely high suspended solids values. The TSS value for Meredosia was 150 mg/liter, the highest value recorded for any lake sampled during 1977. Most of the natural backwater lakes in this group occupy the glacial outwash area adjacent to the Illinois River. These lateral levee lakes have been severely impacted by drainage improvements, levee construction, river dam construction, navigation, and silt deposition. Lack of water clarity is the result of suspended sediment from flowage and resuspension of flocculent bottom materials. Prior to their deterioration, these bottom land lakes supported luxuriant macrophyte populations and fish and invertebrate fauna.

LANDSAT-Estimated Trophic Indicator Classification of the Lakes

In the preceeding subsection the dendrogram generated from the date-adjusted LANDSAT spectral data for the 145 water bodies was interpreted. In this subsection, the results of a parallel effort that employed LANDSAT-derived trophic indicator estimates will be interpreted. Clustering, using trophic indicator estimates derived through conventional lake sampling techniques as attributes, is a well-accepted approach. In this case clustering is based on attributes (i.e., trophic indicators) estimated from the LANDSAT data set.

Four of the trophic indicators (SEC, TPHOS, TON, and CHLA) estimated by the three sets of regression models were selected for cluster analysis. Separate clustering runs were made for each data set using two programs (CLUSTER, a SAS program on COMNET, and CLUSTER, a program on Oregon State University's Cyber 73). While both programs are of the complete linkage type, their hard-copy products and cluster results are similar though not identical.

The regression results indicate that the Set One models are least satisfactory and that the Set Three models provide the best overall estimates. The following interpretation is limited to the Set Three 12-cluster table (Table 24) generated by the SAS program on COMNET. Limnologists found the 12-cluster classification to be more satisfactory than the other groupings examined (e.g., 6- and 9-cluster classifications).

Lake Cluster Characteristics--

In the following subsections an interpretation is made of the 12-cluster SAS program output (Table 24). The cluster characteristics, as evidenced by the 1973 and 1977 contact-sensed data, are given in Table 25. Appendix Tables A-2, A-3, and A-5 list the contact-sensed data for each lake within the clusters. The interpretation is made by comparing: 1) trophic indicator estimates with 1973 NES data; 2) trophic indicator estimates with the 1977 lake water quality data; and 3) the trophic status of the clusters with each other. Clusters are described in order of increasing eutrophy as determined by estimated values for SEC, TON, TPHOS, and CHLA. Terse descriptions for each group are based on cluster means established from estimated values for SEC, TON, TPHOS, and CHLA.

Trophic class number 1 (Cluster 8)--Terse description: (very high SEC, low TON, TPHOS, and CHLA). Lake Kinkaid (serial number 40), a southern Illinois reservoir and the only lake in this class, has excellent water quality (at least for Illinois lakes) with minimal sediment-related turbidity and algal blooms. The aquatic macrophyte problem is rated as slight. Results of IEPA summer 1977 sampling for TSS, VSS, and SEC averaged 1.0 mg/liter, 0.0 mg/liter, and 1.97 m, respectively. Lake Kinkaid has a mean depth of 8.7 m and a maximum depth of 24.4 m; water retention time is 1.72 years.

TABLE 24. TROPHIC CLASSES DEVELOPED FROM CLUSTER ANALYSIS OF TROPHIC INDICATOR ESTIMATES FROM SET THREE REGRESSION MODELS

Name	Serial Number	County
Class 1 (Cluster 8)		
Kinkaid	40	Jackson
Class 2 (Cluster 7)		
Lincoln Trail	13	Clark
Sara	26	Effingham
Little Grassy	119	Williamson, Jackson
Devil's Kitchen	128	Williamson
Glen O. Jones	110	Saline
Coal City Recreation	138	Grundy
South Wilmington	140	Grundy
Thunderbird	173	Putnam
Murphysboro	37	Jackson
Dutchman	49	Johnson
Bracken	145	Knox
St. Mary's	146	Lake
Olney East Fork	106	Richland
Lake of Egypt	132	Johnson, Williamson
George	108	Rock Island
Mesa	184	Wabash
Sand	147	Lake
West Loon	156	Lake
Deep	150	Lake
Class 3 (Cluster 5)		
Paris Twin	25	Edgar
Spring Arbor	143	Jackson
Olney New	107	Richland
Moses	28	Franklin
West Frankfort New	31	Franklin
Cedar	55	Lake
Gages	152	Lake
Catherine	58	Lake
Zurick	154	Lake
Storey	50	Knox

(continued)

TABLE 24. (continued)

Name	Serial Number	County
Crab Orchard	127	Williamson
East Loon	53	Lake
Summerset	186	Winnebago
Channel	59	Lake
Pierce	130	Winnebago
Sam Dale	124	Wayne
Highland	153	Lake
Countryside	148	Lake
Class 4 (Cluster 6)		
Carlyle	14	Clinton, Bond, Fayette
Mattoon	24	Cumberland
Canton	36	Fulton
Commonwealth Edison-Dresden	137	Grundy, Will
We-Ma-Tuk	33	Fulton
Cedar	39	Jackson
Vandalia (City)	27	Fayette
Rend	29	Franklin, Jefferson
Shelbyville	114	Shelby, Moultrie
Wolf	17	Cook
Stephen A. Forbes	78	Marion
Apple Canyon	144	Jo Daviess
McCullom	159	McHenry
Centralia	79	Marion
Bangs	56	Lake
Round	66	Lake
Crystal	68	McHenry
Diamond	57	Lake
Pana	113	Shelby, Christian
Argyle	157	McDonough
Paradise	15	Coles
Big	176	Schuyler
Upper Smith	180	Scott, Morgan
Spring	67	McDonough
Little Swan	185	Warren
Big	134	Brown
Raccoon	80	Marion
Quiver	90	Mason
New Pittsfield	100	Pike
Pistakee	65	Lake, McHenry

(continued)

TABLE 24. (continued)

Name	Serial Number	County
Powerton Cooling	182	Tazewell
Pinckneyville	99	Perry
Lower Smith	181	Scott
Class 5 (Cluster 4)		
Spring	8	Carroll
Charleston	16	Coles
Clear	86	Mason
Chautauqua	87	Mason
Anderson	34	Fulton
Fourth Lake	151	Lake
Meredosia	10	Cass, Morgan
Calumet	18	Cook
Chain	83	Mason
Matanzas	89	Mason
Sugar Creek	178	Schuyler
Old Ben Mine	32	Franklin
Harrisburg	111	Saline
Snyder's Hunting	142	Jackson
Griswold	158	McHenry
Fyre	170	Mercer
Sanganois	9	Cass
Crane	85	Mason
Long	177	Schuyler
Moscow	164	Mason
Yorkey	179	Schuyler
Pekin	116	Tazewell
Kinneman	168	Massac
Lily	136	Cass
Lyerla-Autumnal	120	Union
Tampier	23	Cook
Otter	167	Mason
Sunfish	126	Whiteside
Liverpool	88	Mason
Bath	166	Mason
Swan	93	Mercer
Sahara Coal Company	175	Saline
Goose (Village Club)	139	Grudy

(continued)

TABLE 24. (continued)

Name	Serial Number	County
Class 6 (Cluster 1)		
Horseshoe	1	Alexander
Worley	117	Tazewell
Cattail	125	Whiteside
Bakers	19	Cook
Keithsburg	92	Mercer
Open Pond (Marshy)	174	Saline
Lake of the Woods	115	Tazewell
West Frankfort Old	30	Franklin
Marion	129	Williamson
Sam Parr	41	Jasper
Greenville New City	2	Bond
Nippersink	63	Lake
Decatur	73	Macon
Long	52	Lake
Fox	60	Lake
Grass	61	Lake
Petite	64	Lake
Holiday	51	LaSalle
Third	155	Lake
DePue	3	Bureau
Jack, Swan, and Grass	165	Mason
Crooked	149	Lake
Carbondale	38	Jackson
Rice	35	Fulton
Marie	62	Lake
Spring	118	Tazewell
Senachwine	104	Putnam
Mound	163	Mason
Class 7 (Cluster 2)		
Spring	4	Bureau
Skokie Logoons	22	Cook
Turner	102	Putnam
Class 8 (Cluster 3)		
Saganashkee	21	Cook
Marshall	81	Marshall

(continued)

TABLE 24. (continued)

Name	Serial Number	County
DuQuoin	98	Perry
Goose	100	Putman, Bureau
Swan	172	Putnam
Class 9 (Cluster 11)		
Wonder	69	McHenry
Class 10 (Cluster 12)		
Sawmill	103	Putnam
Class 11 (Cluster 9)		
McGinnis	20	Cook
LaRue-Pine Hills	121	Union
Class 12 (Cluster 10)		
Slocum	54	Lake

Trophic class number 2 (Cluster 7)--Terse description: (high SEC, low TON, TPHOS, and CHLA). Most of the 19 lakes in this group are artificial reservoirs in northern and southern Illinois of good to excellent water quality; these lakes exhibit little use impairment from sediment-related turbidity, algae, or aquatic macrophytes as assessed by IEPA (1978a). The mean depth for the cluster averages 5.7 m and the maximum depth averages 13.8 m. The average detention time for this group is 3.45 years. These lakes are generally clear with very low suspended solids levels. The summer 1977 sampling by IEPA produced mean values of 3.7 mg/liter, 2.7 mg/liter, and 2.06 m for TSS, VSS, and SEC, respectively, for this group.

Trophic class number 3 (Cluster 5)--Terse description: (average SEC, TON, and CHLA, slightly low TPHOS). This class contains southern and northern reservoirs and glacial lakes of good quality with little use impairment from sediment-related turbidity. Algal bloom problems are slight with aquatic vegetation problems ranging in severity from slight to moderate.

TABLE 25. INTERPRETATION OF CLUSTERS DEVELOPED FROM SET THREE REGRESSION MODELS*

			Observed Problems			NES Data (1973)				IEPA Data (1977)							Morphology		Hydrology		Set Three Models			
	Cluster Number and (Obs.)	Perceived Quality	Sediment	Algae	Macro-phyte	SEC	CHLA	TPHOS	TON	SEC	TPHOS	IN	TSS	VSS	ALGAE	$\bar{Z}$	Z_m	Watershed Equivalent Centimeters	Detention Time	SEC	CHLA	TON	TPHOS
1	8 (1)	1.0	1.0	1.0	2.0	-	-	-	-	1.97	0.01	0.13	1	0	264	8.7	24.4	56.9	1.72	7.42	1	0.41	0.02
2	7 (19)	1.6	1.3	1.7	2.4	-	-	-	-	1.83	0.03	0.03	5	4	1,022	5.7	13.8	81.4	3.45	1.84	10	0.82	0.11
3	5 (18)	2.1	1.7	2.4	2.6	1.23	27	0.10	1.08	0.95	0.07	0.19	10	8	4,689	3.0	9.8	28.1	1.14	1.03	28	1.22	0.20
4	6 (33)	2.4	2.3	2.1	2.0	0.58	21	0.12	0.92	1.05	0.06	0.18	19	8	3,290	3.1	8.9	34.3	1.35	0.68	17	0.89	0.15
5	4 (33)	3.4	3.1	1.9	1.7	0.25	18	0.21	1.20	0.31	0.25	1.94	55	22	35,648	1.6	3.8	29.2	1.28	0.35	23	1.20	0.36
6	1 (28)	3.1	2.8	2.8	1.9	0.37	49	0.37	1.59	0.74	0.48	0.79	32	19	5,106	2.0	5.2	41.8	1.86	0.43	42	1.52	0.38
7	2 (3)	4.0	3.5	1.7	1.7	-	-	-	-	0.25	1.17	0.10	37	22	13,824	.8	1.8	-	-	0.28	42	2.12	0.75
8	3 (5)	3.0	3.0	2.3	2.0	-	-	-	-	0.28	0.42	0.13	62	24	1,280	1.2	4.5	9.2	.39	0.32	74	1.91	0.51
9	11 (1)	3.0	3.0	3.0	3.0	0.46	198	0.42	1.79	0.31	0.61	0.16	49	16	2,247	2.0	10.4	12.6	.62	0.31	158	2.07	0.47
10	12 (1)	4.0	4.0	1.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	143	3.00	0.91
11	9 (2)	3.0	1.5	3.5	4.0	-	-	-	-	-	-	-	-	-	-	0.5	1.5	9.0	.45	0.27	109	4.69	1.60
12	10 (1)	4.0	4.0	4.0	1.0	0.31	241	1.33	5.94	0.34	1.50	0.57	25	21	30,465	1.2	2.7	4.8	.24	0.34	229	5.12	1.43

* Parameter means were constructed for 12 clusters.
Parameters, acronyms, and units are as follows:
Trophic Class - based on cluster means of estimated values for SEC, TON, TPHOS, and CHLA, Scaled 1 - 12 with 1 = least eutrophic and 12 = most eutrophic.

Perceived quality - Summary of quality based upon analysis of information from a variety of sources. Scaled 1 - 4 with 1 = very good and 4 = very poor.

Observed Problems - Problems noted through field observations and adversely affecting use. Scaled 1 - 4 with 1 = minimal problem and 4 = severe problem.

NES data (1973) - Data collected by U.S. EPA's National Eutrophication Survey in October 1973. SEC - (meters). CHLA - (μg/liter). TPHOS - mg/liter). TON - (mg/liter).

IEPA Data (1977) - Data collected by Illinois Environmental Protection Agency during summer of 1977. TSS - total suspended solids (mg/liter). VSS - volatile suspended solids (mg/liter). SEC - Secchi depth (meters). TPHOS - total phosphorus (mg/liter). IN - inorganic nitrogen (mg/liter). Algae - algal enumeration (cells x 1000/ml).

Morphology - Data from IEPA files. $\bar{Z}$ - mean depth (meters). Z_m - maximum depth (meters).

Hydrology - Data from IEPA files. Detention time (years).

Set Three Models - cluster means based on parameter estimates generated from the third set of regression models. SEC - Secchi depth (meters). CHLA - chlorophyll a (μg/liter). TON - total organic nitrogen (mg/liter). TPHOS - total phosphorus (mg/liter).

Mean depths for the group average 3.0 m, while maximum depths average 9.8 m. Water detention time averages 1.14 years for the group. According to IEPA 1977 summer sampling data, the average amount of total and volatile suspended matter is three times that of trophic class 2, resulting in a 50 percent decrease in Secchi transparency.

Trophic class number 4 (Cluster 6)--Terse description: (low SEC, TON, TPHOS, and CHLA). The 33 water bodies in this category include reservoirs from throughout the State, glacial lakes, and backwaters, ranging in water quality from fair to good. Sediment-related turbidity is a slight to moderate problem. Algal blooms are a slight problem. Aquatic macrophyte problems are minimal. The mean depth of the cluster members is 3.1 m, while the maximum depth averages 8.9 m. Average water detention time is 1.35 years. Average water transparency and volatile suspended solids concentrations for this group in 1977 were approximately the same as trophic class 3, while the inorganic suspensoid level is three times that of the previous class.

Trophic class number 5 (Cluster 4)--Terse description: (low SEC, slightly low TON and CHLA, average TPHOS). Most of the 20 water bodies included in trophic class 5 are river backwaters or bottom land lakes that are shallow and turbid. Mean depth for the group averages 1.6 m, while maximum depth averages 3.8 m. Most are of poor to fair quality with severe sediment-related turbidity problems. Algal problems are slight and aquatic vegetation is minimal, largely a consequence of the light inhibition by suspended sediment. Summer 1977 sampling data for total and volatile suspended solids show a three-fold increase over the previous trophic class, resulting in a three-fold reduction in Secchi transparency.

Trophic class number 6 (Cluster 1)--Terse description: (low SEC, average TON, TPHOS, and CHLA). This class is represented by river backwaters, reservoirs located throughout the State, and glacial lakes. Most of the water bodies are of fair quality with sediment-related turbidity problems ranging from slight to severe. Algal bloom problems range in severity from slight to moderate. Use impairment from aquatic macrophytes is minimal. Summer 1977 sampling results for total and volatile suspended solids and Secchi depth for this class fall between the average values for trophic classes 4 and 5.

Trophic class number 7 (Cluster 2)--Terse description: (low SEC, moderately high TON and TPHOS, average CHLA). The three water bodies in this class represent a glacial lake, a former sewage lagoon, and a river backwater. These shallow water bodies are of poor quality. Severe sediment-related turbidity and algal bloom problems exist. Vegetation problems are minimal. This class, as well as the remaining five trophic classes, had high suspended solids levels and low Secchi transparency in the IEPA's 1977 summer sampling.

Trophic class number 8 (Cluster 3)--Terse description: (low SEC, moderately high TON and TPHOS, very high CHLA). This group consists of three river backwaters, a northern slough, and a southern reservoir. As presently constituted, quality of these shallow, short-detention water bodies ranges from poor to fair. Sediment-related turbidity ranges from minimal to moderate. Algal blooms and aquatic vegetation present slight use impairment problems.

Trophic class number 9 (Cluster 11)--Terse Description: (low SEC, moderately high TON and TPHOS, very high CHLA). The single water body in this class is a shallow, short-detention, northern reservoir, Wonder Lake (serial number 69). Sediment-related turbidity, algal blooms, and aquatic macrophytes all present moderate use impairment problems for this lake.

Trophic class number 10 (Cluster 12)--Terse description: (low SEC, high TON and TPHOS, very high CHLA). Sawmill Lake (serial number 103) is a river backwater of poor quality as evidenced by severe use impairment problems from sediment-related turbidity and algal blooms. Aquatic vegetation problems are minimal.

Trophic class number 11 (Cluster 9)--Terse description: (low SEC, very high TON and TPHOS, moderately high CHLA). This group consists of La Rue-Pine Hills Swamp (serial number 121), in southern Illinois, and McGinnis Slough (serial number 20), in northern Illinois. Quality of these shallow water bodies is rated as fair with moderate to severe algal blooms, moderate aquatic macrophyte problems, and minimal to slight sediment-related turbidity.

Trophic class number 12 (Cluster 10)--Terse description: (low SEC, very high TON, TPHOS, and CHLA). Slocum Lake (serial number 54) is a shallow, short-detention, northern Illinois reservoir noted for its poor quality. Severe sediment-related turbidity problems and algal blooms are known to exist. Aquatic macrophytes present a minimal problem. Summer 1977 sampling results indicate that practically all of the turbidity is caused by organic particulate matter.

GENERAL DISCUSSION

Although LANDSAT had been used successfully several times in studies of lake eutrophication, and statistically significant relationships between MSS data and lake water quality parameters have been demonstrated, it was not at all certain that such relationships or correlations would eventually be obtained for Illinois lakes. While many of the lakes included in LANDSAT investigations (e.g., Boland 1976) were characterized by low suspended solids and color, Secchi depths greater than several meters, and low to high nutrient concentrations, most Illinois lakes are characterized as turbid with high sediment loads, low mean morphometric and Secchi depths, very high nutrient levels, and short hydraulic retention times. Indeed, whereas many of the lakes studied previously with LANDSAT have primary production that is nutrient limited, most Illinois lakes are nutrient rich, but light poor, as a result of turbidity from suspended inorganic and organic particulate matter.

A major consequence of sediment pollution in Illinois lakes, as it relates to MSS data, is that the majority of observed chemical values are represented within a small range. Further, some of the lakes have extreme levels for some contact-sensed parameters, which are not readily measured with the multispectral scanner. Lake parameters operate over a very large dynamic range in comparison with the range of the MSS. Consequently, analysis of MSS data and lake properties is more sensitive to changes in midrange values. In spite of this loss in statistical sensitivity, MSS data were used to cluster lakes into physically significant groups and to estimate trophic parameters from which clusters were developed.

It is not surprising, therefore, that Set One models, employing raw MSS data to estimate trophic index parameters, are the least reliable, while Set Three models, employing an expansion that makes the MSS data uniform over its entire range, are best. That is, as the concentration increases at a given wavelength, the optical density (reflectance) falls off nonlinearly, with the slope rising fastest at low densities and falling off to near zero at high densities; the optical density scale is logarithmic. The technique used in developing Set Three models, of converting optical densities to ranks, linearizes the slope over the entire range of lakes. Provided that the optical density remains single-valued in the tails and that some discrimination remains, conversion to ranks should be satisfactory, as has been observed.

The application of clustering algorithms to the raw LANDSAT multispectral data proved to be a viable approach, resulting in lake clusters with their own spectral properties and physically significant characteristics. It permited the selective comparison of four band readings, allowing an objective differentiation of water types according to signatures based on a spectral index. In general, increases in spectral responses in any MSS band or combination of bands are associated with greater suspended or soluble material levels and poorer water quality. Lakes having similar spectral band DN readings are closely related in physical and chemical quality. Although actual concentrations of non-sensible constituents are difficult to accurately predict from the LANDSAT MSS data, the spectral responses of the lakes demonstrate general trends with the contact-sensed data. The application of a clustering algorithm to the spectral data in an unsupervised mode has much intuitive appeal; it is simple and deals directly with the spectral characteristics and physical water properties of the lakes.

The application of clustering algorithms to lake attributes whose values have been estimated through regression models incorporating the LANDSAT MSS bands as independent variables is attractive because a statistically significant relationship has been demonstrated to exist between the contact-sensed and remotely sensed data. However, at least in this study, superimposed on the estimated values of the attributes is a substantial amount of unexplained variation. Clustering on such data sets results in groups or clusters whose memberships become increasingly suspect as the unexplained variation associated with the regression modeling efforts increases. Conversely, the more adequate the regression models, the more confidence can be placed in the membership of the individual cluster.

Whether clustering on spectral attributes (e.g., LANDSAT bands) or trophic attributes (e.g., trophic indicators estimated by regression on

LANDSAT bands), the type of clustering method selected will, to some undefined degree, mold the character of the final output. We know of no systematic study that has attempted or is attempting to compare lake classifications derived from different SAHN methods. Standardization and transformation techniques also affect the resulting classifications; this is another area in which little systematic work has been done using lakes.

While it is evident in light of the above discussion that each clustering method has a bias, the clusters developed in this study can be interpreted in "real world" terms. It is clear from our analyses that Illinois lakes represent a much greater diversity of waters than is generally recognized. Further, although a great many of these are "polluted" in the sense of high nutrient enrichment, it is also true that some are "clean water" waters, with aesthetically pleasing qualities. Further, Illinois lakes offer the recreationist diversified opportunities ranging from canoeing, boating, and swimming, to fishing, trapping, bird watching, and wildlife observation.

More pragmatically, cursory comparisons of the 1973 and 1977 data bases show few general changes, either for the better or worse, in these impoundments. Since lakes are dynamic, and Illinois lakes with their relatively short detention times particularly so, it is suggested that lake hydraulic and morphologic factors and land use factors that determine lake water quality, in part, have remained relatively unchanged during the period. Stream water quality, by contrast, has improved overall since 1973 (Hudson et al. 1978).

There are several advantages to using LANDSAT in place of conventional lake monitoring. These include cost, resource requirements, timeliness of the data, uniformity, objectivity, and flexibility of data formats.

The costs of purchasing the CCT's, extracting the lake pixels and associated processing, and preparing statistical and photographic displays for the group of approximately 150 lakes averaged under $200 per lake. A substantial portion of the cost can be attributed to the batch operation mode used to extract most of the lake MSS data. It was very time consuming and laborious, requiring the expenditure of many manhours of effort. With the current availability of the interactive programs described earlier in this report, substantial reductions in extraction costs occur, accompanied by a major reduction in turnaround time. A supplemental LANDSAT study of 60 Illinois lakes cost about $80 per lake for MSS processing. Total costs will probably not exceed $250 per lake.

If relative lake information is required, standard, low-cost, readily available, statistical computer programs can be used to analyze the spectral data. If trophic indicator information is required, some contact-sensed information would have to be acquired at the time of the satellite's passage over the State. Using the methods described in this report, estimates of average lake water quality could be obtained. We estimate the total per lake cost of the present project at $500, and a total project cost of $75,000, including preparation of this report.

In contrast to this, the 1977 lake study involving 108 lakes cost $36,600 for sampling 3 sites per lake and lab analyses. To this must be added the costs for the full-time limnologist, data processing and analyses, and report preparation, which are at least equal to the sampling costs. Therefore, the cost per lake for the conventional approach is at least one-third higher than the LANDSAT approach. However, a word of caution is in order when examining such comparisons. While both approaches (LANDSAT, conventional field program) have the same general objective -- the classification of lakes according to trophic state -- the quality and types of products generated, the parameters measured and their associated accuracies and precisions, and temporal efficiencies are generally not the same. In addition, this was a prototype study for the Illinois Environmental Protection Agency. As such, it had a "learning curve" associated with it, lacked the streamlining characteristic of operational programs, and, therefore, incurred costs in time and money that are above those for a program functioning at an optimal level.

This study strongly supports the value and cost effectiveness of LANDSAT for lake monitoring. When this is coupled with the sophistication available in false-color imagery, many specific questions about the instantaneous or dynamic conditions of selected lakes can be examined. This project has served to increase our understanding of a substantial number of Illinois water bodies. For the first time a quantitative, geographically comprehensive understanding of these bodies is available. As our understanding improves, rational decisions concerning the uses and fates of these lakes can be made, costs determined, programs implemented, and benefits accrued and assessed.

Problems

By virtue of its repetitive coverage, synoptic overview, and ability to generate permanent records amenable to automated image-processing techniques, the LANDSAT MSS is attractive for purposes of environmental assessment and monitoring. In this study LANDSAT provided a view of the past; it does provide a monitoring strategy that is objective, uniform, frequent, resource tolerant, and cost effective for the future. However, LANDSAT is not a panacea; it has limitations and problems associated with it. A number of problems were encountered during the study. Several were solved; others, by virtue of their nature, defied solution. Not all are mutually exclusive. The specific problems are discussed in the following subsections.

Availability of Imagery--

Ten LANDSAT MSS scenes are required for complete areal coverage of Illinois. This necessitates that the satellite make three passes over the State, once on each of three paths (Figure 19). In 1973, only LANDSAT-1 coverage was available for the Illinois lakes. Excluding side overlap, the satellite provided coverage on a repetitive 18-day basis. It was our intention to use MSS data acquired concurrently with one of the three NES sampling rounds, preferably the summer round. The occurence of substantial areas of cloud cover in numerous LANDSAT scenes acquired between April and November of 1973 restricted us to the scenes of October 14, 15, and 16, 1973.

Cloud cover will continue to plague water and terrestrial studies dependent upon LANDSAT data. Unlike aircraft, LANDSAT is locked into a fixed flyover schedule. Although the problem of obtaining good, cloud-free imagery has been reduced by the presence of two currently operational satellites (LANDSAT-2 and LANDSAT-3), it is still a problem of substantial magnitude.

The CCT's for the 10 Illinois scenes, not available at the EROS data Center, had to be generated at NASA-Goddard. This process took several months, with the CCT's for only eight scenes being generated. The long delay in delivery was a consequence of several factors:

1. NASA-Goddard software changes. The generation of our "historic" CCT's from the high-density tapes required that NASA replace its currently operational software with that developed at the start of the LANDSAT program. Difficulties were encountered as a result of hardware and programmatic changes.

2. Deterioration of high density tapes. Although only about three years old, some of the high-density tapes had degraded in quality to the point where reading them became difficult or impossible.

3. Unavailability of spacecraft data. The scene data for scene 1449-16084 were available, but the spacecraft data necessary to calibrate the scene could not be found.

One of the scenes (1449-16084), arrived without the proper internal calibration data. Much time and effort was expended in attempts to calibrate and use the data from this scene. The black-and-white imagery available from EROS for the 10 scenes (Figures 20, 22-30) was originally generated at NASA-Goddard using an electron beam recorder and data on the density tapes. If the difficulties experienced in having "historic" CCT's generated from high density tapes is typical of that experienced by other investigators, the question to ponder becomes: "What will the value of the archived tapes be a decade from now?"

Availability of Interactive Image-Processing System--

At the start of the project, we were limited to an image-processing system that operated in a batch mode (see Section 6). By virtue of its nature, the process of extracting the data for about 150 lakes (many appearing in two or more scenes) using the batch mode is inefficient both timewise and costwise. The development and refinement of the interactive image-processing system (LAKELOC) has greatly speeded up the extraction process. What initially took hours now requires but a few minutes. Placement at the system's controls of an individual knowledgeable about the lakes of Illinois could improve its efficiency even more.

Environmental Factors--

It is well recognized that the atmosphere can have substantial effects on the signal returning from lakes. While the MSS data were adjusted to a common date, October 15, no concentrated effort was made to remove atmospheric effects through the use of theoretical modeling or empirical modeling involving terrestrial or aquatic calibration points. An unknown amount of variation, attributable to the variation in intensity of atmospheric effects across the LANDSAT scenes, exists in the MSS lake data.

During the period of October 11-14, 1973, much of Illinois experienced moderate rains (Figure 64). The amount of precipitation appears to be normal for this season. It is very likely that many of the lakes experienced large influxes of suspended sediments. In some cases, a substantial proportion of each lake's volume was displaced by the incoming waters. The combination of inorganic sediment influx and volume displacement did not disrupt the average characteristics of the water bodies if comparisons of the NES data for the spring and summer of 1973 with 1977 data are representative of the true quality.

At the time of satellite flyover (October 14-16), the solar angle was small, measuring between 35 and 38 degrees. This effectively reduces the amount of light entering the water body, and consequently the intensity of the return signal is less than at higher solar angles. This makes the spectral distinction between lake types a more difficult task because there are fewer DN levels.

The season during which the spectral data are collected has some relationship to the degree of success experienced by LANDSAT-oriented lake classification projects. As suggested by Rogers (1977) and others, success is most likely when the secondary manifestations of eutrophication (e.g., turbidity, algal blooms, macrophyte beds) are most evident. In Illinois water bodies, July and August are probably the best period for attempting satellite-based classifications. Unfortunately, this project was limited by cloud cover and NES sampling dates to the middle of October.

Contact-Sensed Data--

The NES data were collected without any thought being given to their use in a satellite-related lake classification project. Hence, sample site selections were not always optimal in location or number for use with LANDSAT data. In addition, field notes regarding phenomena of special interest (e.g., tubidity plumes, macrophyte beds) were not adequately documented for purposes of this project. Some parameters of particular interest to us (e.g., total suspended solids, volatile suspended solids) were not measured by the NES.

LANDSAT MSS--

The LANDSAT multispectral scanner was not designed specifically with lakes in mind. It is, both spectrally and spatially speaking, a low-resolution sensor. While its gain can be increased in the GRN and RED bands, this project was restricted to the normal gain settings. The "blocky" appearance often evident along the land-water interface can be disconserting to the neophyte user of LANDSAT imagery. Even more distracting, as well as detrimental, is the "sixth line" banding or striping so apparent in MSS imagery of water bodies. Although the trained eye can overlook the striping, it is distracting. More importantly, it represents data values that increase the variance, thereby adding to the uncertainty of satellite-derived trophic indicator estimates and lake classification products (e.g., thematic photomaps). Attempts to destrip MSS data for water bodies have only been moderately successful.

Multivariate Trophic Indices--

In Section 6 the use of principal components analysis was demonstrated as a means of developing two multivariate trophic state indices (i.e., PC1F5, PC1Y5). The concept has been used previously to rank lakes (e.g., Boland 1976, Brezonik and Shannon 1971, Sheldon 1972). We suggest that a word of caution is in order when examining the resultant ordinations of Illinois lakes. Many Illinois water bodies are turbid primarily because of inorganic suspended solids that drastically reduce light levels and affect algal and macrophyte productivity. Still other Illinois lakes have turbidity problems caused by algae. It may be more proper to segregate the water bodies into two or more basic groups and then apply the principal components analysis or some other ordination technique. This is one area that should be explored further.

Illinois Lakes Data Base--

Prior to the commencement of this project, the IEPA had assembled very little information on the chemical and biological quality of the State's lakes. With the exception of some scattered reports that were available from other State or Federal agencies on specific lakes, no comprehensive inventory of lake data existed. This information was required to process the MSS tapes and to interpret and evaluate the classification results. The task of assembling and verifying the necessary data was laborious and took several months. Furthermore, quality control and comparability problems arise when using data from several different sources.

At the onset of this project, the IEPA had no formal program for the monitoring and classification of lakes. While much information was initially available from numerous individuals within the Agency, it took a substantial amount of time to consolidate Agency expertise on the condition and nature of Illinois water bodies.

Model Development--

The development of the regression models was no trivial task. The difficulty was caused, in part, by the nonnormality of the ground truth and MSS data, the very limited range of DN levels in the four LANDSAT-1 MSS bands, and the receipt of faulty MSS data for scene 1449-16084. The models are specific to the set of scenes from which they were developed. It is unlikely that they will yield satisfactory results if applied to other LANDSAT scenes. However, the overall approach is applicable to lakes in other geographic areas and to satellite MSS data collected at other times.

Whether employing regression analysis or clustering techniques, the use of average DN values for each spectral band for a lake does not account for the spectral variability for a specific portion of a lake and its associated trophic condition. Thus, lake characterization using average spectral responses affords, at best, the average lake response but provides no information about its variability. This information is revealed through the analysis of band DN histograms, or by optical techniques that convert the differing DN values into a false-color image. Information regarding variability within lakes was not obtained in this study.

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APPENDIX

MEASURED AND ESTIMATED WATER QUALITY DATA FOR SELECTED ILLINOIS WATER BODIES

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TABLE A-1. UNADJUSTED AND ADJUSTED MULTISPECTRAL SCANNER DATA FOR ILLINOIS WATER BODIES (OCTOBER 14, 15, and 16, 1973)*

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation)			
							GRN	RED	IR1	IR2
Anderson	34		10-15-73	1449-16084	969	620	41.89	30.16	22.63	9.02
							(3.56)	(3.19)	(5.66)	(5.02)
			10-16-73	1450-16142	944	603	42.19	30.63	23.49	9.09
							(2.19)	(1.81)	(3.52)	(4.96)
							+43.26	+30.22	+22.08	+9.30
Apple Canyon	144		10-16-73	1450-16140	240	153	33.22	18.82	15.95	10.81
							(3.15)	(4.11)	(6.38)	(8.13)
							+36.72	+21.03	+17.44	+10.39
Argyle	157		10-16-73	1450-16142	49	31	39.16	26.36	20.32	14.20
							(1.82)	(1.95)	(5.51)	(7.99)
							+41.05	+26.90	+20.13	+12.54
Bakers	19		10-14-73	1448-16023	78	50	46.42	31.56	29.03	11.84
							(2.39)	(2.12)	(3.04)	(5.09)
							+45.51	+30.92	+28.48	+12.13
Bangs	56		10-14-73	1448-16023	191	122	37.36	21.40	14.83	6.20
							(2.17)	(2.78)	(5.32)	(6.29)
							+36.74	+20.60	+15.03	+7.15
Bath	166		10-15-73	1449-16084	97	62	40.33	29.74	28.19	16.02
							(3.86)	(4.06)	(6.92)	(7.35)
			10-16-73	1450-16142	73	47	42.10	31.68	27.71	14.78
							(2.41)	(2.73)	(3.45)	(5.99)
							+43.20	+31.04	+24.68	+12.91

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation)			
							GRN	RED	IR1	IR2
Big	134		10-15-73	1449-16084	149	95	39.66	26.65	25.18	13.56
							(3.56)	(3.60)	(9.85)	(8.11)
			10-16-73	1450-16142	127	81	39.79	28.11	22.48	11.77
							(2.13)	(2.23)	(6.08)	(6.81)
							+41.51	+28.26	+21.46	+11.00
Big	176		10-15-73	1449-16084	117	75	40.66	29.80	26.55	11.70
							(3.95)	(3.44)	(8.80)	(6.53)
			10-16-73	1450-16142	106	68	42.30	31.77	25.03	11.21
							(2.51)	(2.84)	(4.63)	(6.27)
							+43.34	+31.11	+23.03	+10.65
Bloomington	71	1703	10-15-73	1449-16084	374	238	38.87	27.00	24.16	11.78
							(3.65)	(3.94)	(11.50)	(8.42)
Bracken	145		10-16-73	1450-16142	83	53	35.53	19.84	18.28	12.40
							(2.05)	(2.74)	(5.64)	(7.75)
							+38.40	+21.82	+18.87	+11.40
Calumet	18		10-14-73	1448-16023	631	403	52.22	41.40	25.44	10.41
							(3.59)	(3.95)	(4.78)	(6.48)
							+51.13	+40.92	+25.03	+10.87
Canton	36		10-15-73	1449-16084	151	97	41.28	28.19	26.95	12.34
							(4.02)	(3.83)	(12.09)	(7.23)
			10-16-73	1450-16141	128	82	42.40	30.48	21.39	10.75
							(2.74)	(3.57)	(4.95)	(7.25)
							+43.41	+30.10	+20.79	+10.35

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Carbondale	38		10-14-73	1448-16035	45	29	47.22 (2.38) +46.28	34.62 (4.89) +34.03	28.75 (6.09) +28.22	13.79 (7.71) +13.85
			10-15-73	1449-16093	42	27	45.09 (2.42)	34.19 (3.77)	27.90 (5.58)	13.33 (5.58)
Carlyle	14	1706	10-14-73	1448-16032	15,435	9,864	46.30 (2.36) +45.39	31.66 (2.98) +31.02	18.18 (5.08) +18.20	6.01 (5.22) +6.99
Catherine	58		10-14-73	1448-16023	95	61	35.77 (1.90) +35.20	19.65 (1.84) +18.82	14.96 (5.18) +15.15	6.28 (5.93) +7.22
Cattail	125		10-16-73	1450-16140	30	19	36.83 (2.22) +39.35	26.36 (2.44) +26.90	26.29 (2.79) +23.80	19.69 (5.87) +16.02
Cedar	39		10-14-73	1448-16035	113	72	43.59 (4.54) +42.77	32.15 (7.35) +31.52	23.66 (7.33) +23.40	13.11 (7.35) +13.25
			10-15-73	1449-16093	121	77	40.28 (4.18)	28.87 (6.36)	21.76 (7.03)	12.85 (7.45)
Cedar	55	1759	10-14-73	1448-16023	200	128	34.68 (2.71) +34.14	19.65 (4.17) +18.82	13.58 (6.99) +13.85	6.86 (7.42) +7.74

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation)			
							GRN	RED	IR1	IR2
Centralia	79		10-14-73	1448-16032	144	92	36.47	21.86	17.86	11.38
							(2.37)	(2.98)	(6.12)	(7.84)
							+35.87	+21.06	+17.90	+11.72
Chain, Ingram, Sangamon, Stafford, Stewart, Snicarte	83		10-15-73	1449-16084	427	273	40.27	29.10	25.50	11.59
							(3.28)	(2.84)	(6.72)	(6.01)
			10-16-73	1450-16142	467	298	41.21	30.74	25.88	12.03
							+42.55	+30.30	+23.55	+11.16
Channel	59		10-14-73	1448-16023	221	141	37.51	21.85	16.72	6.72
							(1.74)	(2.71)	(5.13)	(6.49)
							+36.88	+21.05	+10.82	+7.61
Charleston	16	1708	10-14-73	1448-16032	189	121	42.39	30.65	22.51	9.91
							(2.53)	(2.34)	(3.51)	(6.02)
							+41.61	+30.00	+22.31	+10.43
Chautauqua	87		10-15-73	1449-16084	1,610	1,030	42.66	32.41	26.91	11.78
							(3.99)	(4.50)	(4.92)	(3.73)
			10-16-73	1450-16142	1,604	1,025	42.30	32.09	26.17	11.18
							(2.75)	(3.54)	(2.29)	(3.27)
							+43.34	+31.36	+23.73	+10.63
Clear	86		10-15-73	1449-16084	977	625	41.10	30.26	25.67	11.71
							(3.35)	(2.55)	(5.50)	(4.89)
			10-16-73	1450-16142	968	619	41.08	30.46	25.40	11.30
							(2.12)	(1.91)	(2.94)	(4.46)
							+42.45	+30.09	+23.26	+10.70

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Coal City Recreation Club	138		10-14-73	1448-16023	53	34	48.03 (5.31) +47.07	28.90 (4.38) +28.22	22.90 (6.48) +22.68	16.73 (7.83) +16.44
			10-15-73	1449-16082	51	33	48.43 (5.35)	28.41 (4.21)	22.56 (6.13)	16.54 (7.29)
Commonwealth Edison-Dresden Nuclear	137		10-14-73	1448-16023	720	460	41.26 (3.40) +40.51	29.34 (3.42) +28.66	17.32 (4.94) +17.39	6.71 (5.31) +7.60
			10-15-73	1449-16082	720	460	41.31 (3.49)	29.56 (3.56)	17.53 (4.93)	7.18 (5.19)
Countryside	148		10-14-73	1448-16023	80	51	38.16 (1.34) +37.51	22.34 (1.40) +21.55	18.15 (4.53) +18.18	8.84 (6.99) +9.48
Crab Orchard	127	1712	10-14-73	1448-16035	4,198	2,683	39.15 (2.29) +38.47	24.32 (2.67) +23.56	17.36 (5.33) +17.43	6.76 (6.33) +7.65
Crane	85		10-15-73	1449-16084	1,212	776	43.71 (4.90)	34.11 (6.41)	27.69 (6.39)	11.63 (4.47)
			10-16-73	1450-16142	1,589	1,015	44.83 (3.84) +45.19	35.54 (5.43) +34.04	27.79 (3.41) +24.73	12.34 (4.16) +11.36
Crooked	149		10-14-73	1448-16023	84	54	45.82 (1.80) +44.93	26.64 (1.62) +25.92	24.54 (4.15) +24.23	9.74 (5.75) +10.28

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation)			
							GRN	RED	IR1	IR2
Crystal	68		10-15-73	1449-16082	146	93	36.69	20.78	15.21	8.02
							(1.98)	(2.90)	(5.93)	(6.39)
Dawson	70		10-15-73	1449-16084	105	67	37.47	25.26	27.70	15.18
							(3.23)	(4.09)	(13.88)	(13.73)
Decatur	73	1714	10-14-73	1448-16032	1,778	1,136	39.78	27.83	18.60	7.49
							(2.33)	(2.35)	(4.59)	(6.03)
							+39.08	+27.13	+18.60	+8.29
			10-15-73	1449-16084	1,862	1,192	38.38	27.30	21.74	9.84
							(3.62)	(3.28)	(8.45)	(6.68)
Deep	150		10-14-73	1448-16023	136	87	36.80	19.86	12.85	6.03
							(1.49)	(2.11)	(4.98)	(6.00)
							+36.19	+19.03	+13.16	+7.00
DePue	3	1752	10-15-73	1449-16082	360	230	41.06	29.52	22.53	10.59
							(2.51)	(2.18)	(4.30)	(6.23)
			10-16-73	1450-16140	373	238	39.38	29.80	23.90	11.84
							(2.53)	(2.37)	(3.38)	(5.61)
							+41.21	+29.57	+22.33	+11.04
Devil's Kitchen	128		10-14-73	1448-16035	370	236	34.07	17.48	15.30	9.89
							(1.81)	(2.07)	(6.46)	(7.85)
							+33.55	+16.61	+15.48	+10.41

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Diamond	57		10-14-73	1448-16023	95	61	39.03 (2.00) +38.35	22.75 (2.39) +21.97	15.63 (5.45) +15.79	6.74 (6.86) +7.63
DuQuoin	98		10-14-73	1448-16035	86	55	34.59 (3.28) +34.05	20.81 (4.05) +20.00	18.53 (7.41) +18.54	10.97 (8.42) +11.36
			10-15-73	1449-16093	81	52	32.97 (2.61)	19.76 (3.87)	17.55 (6.59)	10.16 (7.52)
Dutchman	49		10-14-73	1448-16035	26	17	37.80 (2.45) +37.16	21.42 (2.51) +20.62	18.42 (6.95) +18.43	11.65 (8.30) +11.96
East Loon	53	1757	10-14-73	1448-16023	105	67	35.27 (1.74) +34.71	20.85 (2.32) +20.04	15.88 (5.91) +16.03	8.53 (6.84) +9.21
Evergreen	72		10-15-73	1449-16084	466	298	36.88 (3.70)	23.40 (5.07)	21.80 (11.99)	10.77 (7.45)
Fourth	151		10-14-73	1448-16023	200	128	42.37 (2.14) +41.59	30.04 (1.57) +29.38	21.63 (3.89) +21.47	8.53 (6.27) +9.21
Fox	60	1755	10-14-73	1448-16023	1,159	741	39.92 (2.27) +39.22	26.67 (1.98) +25.95	17.99 (3.85) +18.02	6.09 (5.06) +7.06

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Fyre	170		10-16-73	1450-16140	60	38	32.94 (2.40) +36.52	19.18 (3.25) +21.31	17.84 (6.80) +18.60	11.76 (8.19) +10.99
Gages	152		10-14-73	1448-16023	83	53	36.16 (1.76) +35.57	20.38 (2.12) +19.56	14.01 (5.09) +14.25	6.28 (5.43) +7.22
George	108		10-16-73	1450-16140	89	57	35.43 (1.68) +38.33	19.55 (2.18) +21.60	15.87 (6.00) +17.39	10.62 (8.21) +10.27
Glen O. Jones	110		10-14-73	1448-16035	61	39	36.91 (2.53) +36.30	19.86 (3.16) +19.03	15.32 (6.15) +15.50	9.02 (7.17) +9.64
Goose (Sparland Conservation Area)	82		10-15-73	1449-16084	604	387	42.58 (3.55)	34.18 (4.15)	27.51 (5.09)	12.80 (4.53)
Goose	101		10-15-73	1449-16082	1,088	696	42.67 (1.96)	31.37 (1.73)	24.88 (2.82)	11.06 (4.03)
			10-16-73	1450-16140	1,160	741	40.60 (2.00) +42.10	31.93 (1.77) +31.22	28.04 (2.03) +24.88	16.56 (3.63) +14.04

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Goose (Village Club)	139		10-14-73	1448-16023	116	74	45.05 (6.79) +44.18	31.40 (7.63) +30.76	24.10 (7.98) +23.81	17.05 (8.10) +16.73
			10-15-73	1449-16082	117	75	45.01 (6.72)	31.92 (8.03)	25.13 (8.14)	17.97 (7.39)
Grass	61	1756	10-14-73	1448-16023	1,025	655	37.61 (1.69) +36.98	25.95 (2.20) +25.22	17.38 (4.11) +17.45	7.00 (5.79) +7.86
Greenville New City (Governor Bond)	2		10-14-73	1448-16032	482	308	38.52 (2.41) +37.86	24.90 (2.76) +24.15	18.43 (5.73) +18.44	8.90 (7.22) +9.54
Griswold	158		10-15-73	1449-16082	30	19	36.59 (2.39)	22.49 (2.45)	19.66 (5.27)	11.69 (6.09)
Harrisburg	111		10-14-73	1448-16035	94	60	36.08 (3.63) +35.50	22.34 (4.09) +21.55	18.10 (7.12) +18.13	10.64 (7.64) +11.07
Highland (Old Taylor	153		10-14-73	1448-16023	65	42	33.52 (1.58) +33.02	17.87 (1.60) +17.01	12.61 (4.65) +12.93	5.80 (5.89) +6.80
Holiday	51	1754	10-15-73	1449-16082	186	119	35.36 (1.98)	22.09 (2.14)	17.15 (4.97)	8.65 (6.19)

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Horseshoe	1		10-15-73	1449-16093	262	168	38.72 (5.13)	25.28 (6.47)	23.12 (8.29)	12.57 (8.39)
Jack, Swan, Grass	165		10-15-73	1449-16084	927	593	39.32 (3.22)	27.39 (2.41)	23.62 (6.90)	10.56 (5.89)
			10-16-73	1450-16142	859	549	39.49 (1.97) +41.29	28.57 (1.86) +28.62	23.27 (3.63) +21.94	9.99 (4.93) +9.87
Keithsburg National Wildlife Refuge	92		10-16-73	1450-16142	126	81	36.85 (1.77) +39.37	25.34 (1.62) +26.10	25.76 (4.61) +23.48	19.80 (6.16) +16.09
Kinkaid	40		10-14-73	1448-16035	1,338	855	37.43 (4.71) +36.80	22.52 (6.75) +21.73	17.22 (7.82) +17.30	9.26 (7.71) +9.85
			10-15-73	1449-16093	1,371	876	42.03 (4.20)	21.13 (5.29)	16.07 (7.27)	8.76 (7.77)
Kinneman	168		10-14-73	1448-16035	36	23	50.08 (4.69) +49.05	33.44 (5.00) +32.83	30.44 (5.87) +29.55	20.33 (4.93) +19.62
Lake of Egypt	132		10-14-73	1448-16035	1,186	758	39.75 (4.67) +39.05	23.72 (4.66) +22.95	17.03 (6.48) +17.12	9.41 (7.54) +9.99

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Lake of the Woods	115		10-15-73	1449-16084	65	42	40.65	29.42	29.51	15.85
							(3.99)	(3.97)	(6.84)	(6.52)
			10-16-73	1450-16142	58	37	40.44	29.96	27.75	13.77
							(2.90)	(2.70)	(3.63)	(5.29)
							+41.99	+29.70	+24.70	+12.27
LaRue-Pine Hills Ecological area	121		10-14-73	1448-16035	18	12	37.94	24.05	29.22	23.27
							(2.37)	(3.66)	(4.05)	(5.02)
							+37.30	+23.29	+28.66	+22.21
Lily	136		10-15-73	1449-16084	102	65	43.84	34.94	36.76	17.62
							(4.12)	(4.89)	(10.50)	(6.31)
			10-16-73	1450-16142	85	54	44.32	36.69	30.17	16.69
							(2.08)	(2.99)	(3.95)	(5.71)
							+44.81	+34.93	+26.19	+14.12
Lincoln Trail State Park	13		10-14-73	1448-16032	73	47	34.34	17.72	15.60	10.30
							(2.54)	(2.56)	(6.01)	(6.35)
							+33.81	+16.86	+15.76	+10.77
Little Grassy	119		10-14-73	1448-16035	522	334	35.30	18.56	14.27	8.39
							(2.22)	(2.45)	(6.53)	(7.72)
							+34.74	+17.71	+14.50	+9.09
Little Swan	185		10-16-73	1450-16142	151	97	40.97	31.39	23.14	12.13
							(1.34)	(1.39)	(3.47)	(4.59)
							+42.37	+30.31	+21.86	+11.23

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation)			
							GRN	RED	IR1	IR2
Liverpool	88		10-15-73	1449-16084	36	23	42.17	30.77	34.57	19.86
							(3.93)	(4.13)	(7.57)	(7.41)
			10-16-73	1450-16142	30	20	43.03	33.83	29.23	16.96
							(2.32)	(2.08)	(3.86)	(5.76)
							+43.87	+32.71	+25.62	+14.29
Long	52	1725	10-14-73	1448-16023	242	155	36.58	23.53	16.40	6.42
							(1.76)	(1.71)	(4.44)	(5.82)
							+35.98	+22.76	+16.52	+7.35
Long	177		10-15-73	1449-16084	77	49	43.12	32.66	30.70	14.51
							(5.08)	(5.83)	(9.20)	(7.28)
			10-16-73	1450-16142	68	44	44.23	34.11	27.80	13.61
							(3.77)	(5.16)	(5.42)	(6.52)
							+44.75	+32.93	+24.73	+12.17
Lower Smith	181		10-15-73	1449-16084	79	51	40.91	29.77	30.04	15.24
							(3.58)	(3.36)	(10.33)	(7.59)
			10-16-73	1450-16142	60	38	42.39	32.18	25.26	14.69
							(2.65)	(2.67)	(3.52)	(6.85)
							+43.41	+31.43	+23.17	+12.85
Lyerla-Autumnal Flooding Ponds	120		10-14-73	1448-16035	345	221	42.31	27.46	24.34	13.71
							(3.68)	(3.30)	(7.04)	(8.03)
							+41.53	+26.75	+24.04	+13.78

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Marie	62	1727	10-14-73	1448-16023	347	222	39.18 (2.19) +38.50	25.04 (2.11) +24.30	19.07 (4.79) +19.05	7.76 (6.23) +8.53
Marion	129		10-14-73	1448-16035	81	52	34.86 (2.05) +34.32	20.24 (2.27) +19.42	18.59 (6.52) +18.59	10.92 (7.37) +11.32
Marshall County Pulic Hunting and Fishing Area	81		10-15-73	1449-16084	1,131	724	39.09 (3.22)	27.38 (2.60)	23.48 (5.70)	10.51 (5.09)
			10-16-73	1450-16142	1,138	729	38.95 (1.86) +40.90	28.87 (2.07) +28.85	24.95 (2.81) +22.98	11.94 (4.54) +11.11
Matanzas	89		10-15-73	1449-16084	242	155	41.79 (3.45)	31.60 (2.60)	24.57 (5.54)	11.43 (6.13)
			10-16-73	1450-16142	236	151	42.08 (2.07) +43.18	31.85 (1.80) +31.17	25.08 (3.14) +23.06	11.12 (5.33) +10.59
Mattoon	24		10-14-73	1448-16032	611	391	42.07 (2.83) +41.30	28.13 (2.69) +27.43	18.31 (6.16) +18.33	8.73 (7.57) +9.39
McCullom	159		10-15-73	1449-16082	168	107	37.08 (2.02)	21.39 (2.35)	17.40 (5.69)	10.38 (7.24)

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
McGinnis (Orland)	20		10-14-73	1448-16023	179	114	37.99 (2.42) +37.35	23.71 (2.42) +22.94	27.59 (4.04) +27.12	13.36 (4.88) +13.47
			10-15-73	1449-16082	160	102	38.35 (1.50)	24.04 (1.46)	28.03 (2.52)	12.89 (4.05)
Meredosia	10		10-15-73	1449-16084	1,100	704	46.36 (5.37)	38.49 (7.29)	28.97 (6.26)	12.81 (6.15)
			10-16-73	1450-16142	965	617	46.85 (4.23) +46.66	39.52 (6.45) +37.14	28.33 (4.60) +25.06	12.01 (5.25) +11.15
Mesa	184		10-14-73	1448-16032	56	36	37.26 (2.04) +36.64	20.80 (2.22) +19.99	15.46 (5.82) +15.63	8.39 (6.83) +9.09
Moscow	164		10-15-73	1449-16084	164	106	40.09 (3.53)	28.15 (3.32)	25.85 (7.21)	12.95 (7.11)
			10-16-73	1450-16142	148	95	40.94 (2.18) +42.35	29.72 (1.82) +29.51	25.06 (3.64) +23.05	12.13 (5.45) +11.23
Moses	28		10-14-73	1448-16035	75	48	33.86 (2.55) +33.35	19.55 (3.11) +18.72	18.06 (6.95) +18.09	11.90 (8.38) +12.18

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation)			
							GRN	RED	IR1	IR2
Mound	163		10-15-73	1449-16084	353	226	36.85	24.57	24.13	11.76
							(3.04)	(2.91)	(9.27)	(6.70)
			10-16-73	1450-16142	329	210	36.46	24.90	21.47	10.75
							(1.52)	(1.80)	(3.74)	(5.82)
							+39.08	+25.76	+20.84	+10.35
Murphysboro	37		10-14-73	1448-16035	74	47	37.29	21.56	16.21	9.04
							(1.60)	(2.02)	(4.80)	(6.24)
							+36.67	+20.76	+16.34	+9.66
			10-15-73	1449-16093	85	54	35.04	19.76	17.32	11.18
							(1.81)	(1.93)	(6.71)	(8.53)
New Pittsfield	100		10-16-73	1450-16142	113	72	45.65	36.75	25.29	11.67
							(3.39)	(5.01)	(4.54)	(6.00)
							+45.78	+34.98	+23.19	+10.94
Nippersink	63		10-14-73	1448-16023	310	198	38.24	25.94	17.51	6.61
							(2.17)	(2.57)	(3.95)	(5.13)
							+37.59	+25.21	+17.57	+7.52
Old Ben Mine	32	1765	10-14-73	1448-16035	44	28	37.97	24.45	20.59	11.63
							(3.06)	(2.82)	(6.99)	(6.89)
							+37.33	+23.70	+20.49	+11.94
Olney East Fork	106		10-14-73	1448-16032	448	286	39.25	22.69	17.28	9.47
							(3.37)	(3.65)	(6.97)	(7.69)
							+38.57	+21.91	+17.35	+10.04

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Olney New	107		10-14-73	1448-16032	68	44	37.54 (2.80) +36.91	22.38 (3.01) +21.59	20.01 (7.27) +19.94	12.99 (7.36) +13.14
Open Pond (Marshy)	174		10-14-73	1448-16035	152	97	40.94 (4.79) +40.20	27.26 (7.72) +26.55	24.74 (8.07) +24.42	17.62 (7.67) +17.23
Otter	167		10-15-73	1449-16084	117	75	36.69 (3.43)	24.22 (3.35)	26.36 (8.43)	16.45 (7.39)
			10-16-73	1450-16142	93	59	36.92 (2.35) +39.42	25.43 (2.89) +26.17	23.08 (4.73) +21.83	15.23 (7.02) +13.19
Pana	113		10-14-73	1448-16032	118	75	41.68 (5.47) +40.92	28.06 (7.81) +27.36	20.73 (7.68) +20.62	12.42 (7.72) +12.64
Paradise	15		10-14-73	1448-16032	88	56	40.70 (1.85) +39.97	27.95 (1.44) +27.25	19.59 (5.33) +19.54	9.10 (7.43) +9.71
Paris Twin	25		10-14-73	1448-16032	111	71	34.98 (2.71) +34.43	20.78 (3.01) +19.97	18.35 (6.61) +18.37	12.22 (7.27) +12.47

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Pekin	116		10-15-73	1449-16084	97	62	41.27 (4.14)	30.62 (4.22)	29.44 (5.76)	17.00 (6.64)
			10-16-78	1450-16142	58	37	42.12 (2.82)	32.32 (2.79)	27.18 (3.97)	14.43 (5.79)
							+43.21	+31.53	+24.35	+12.69
Petersburg	169		10-15-73	1449-16084	89	57	37.06 (5.63)	22.38 (8.23)	25.47 (15.49)	12.40 (7.55)
Petite	64		10-14-73	1448-16023	103	66	39.10 (1.76)	25.50 (1.80)	18.30 (4.36)	7.81 (6.62)
							+38.42	+24.76	+18.32	+8.57
Pierce	130		10-15-73	1449-16082	91	58	37.74 (2.04)	21.96 (2.27)	17.86 (5.59)	9.84 (6.83)
			10-16-73	1450-16140	94	60	33.07 (2.06)	19.39 (2.18)	15.62 (5.21)	8.14 (7.20)
							+36.61	+21.47	+17.23	+8.70
Pinckneyville	99		10-14-73	1448-16035	77	49	41.50 (3.06)	26.28 (2.93)	18.48 (5.06)	8.47 (7.09)
							+40.75	+25.56	+18.49	+9.16
			10-15-73	1440-16093	77	49	39.16 (3.00)	24.51 (2.93)	18.40 (5.56)	8.87 (7.02)
Pistakee	65	1733	10-14-73	1448-16023	1,067	682	37.73 (1.72)	23.79 (2.08)	16.88 (4.50)	6.55 (5.89)
							+37.08	+23.02	+16.97	+7.46

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Powerton Cooling	182		10-15-73	1449-16084	893	572	36.89	22.33	16.63	6.94
							(3.81)	(4.36)	(7.54)	(4.75)
			10-16-73	1450-16142	928	593	36.33	22.54	16.04	5.90
							(2.34)	(2.90)	(3.78)	(4.54)
							+38.99	+23.92	+17.49	+7.28
Quiver	90		10-15-73	1449-16084	216	138	40.13	30.59	26.47	13.84
							(3.56)	(4.23)	(6.11)	(7.33)
			10-16-73	1450-16142	210	134	39.90	30.43	22.59	11.29
							(2.61)	(3.15)	(5.24)	(6.96)
							+41.59	+30.06	+21.53	+10.70
Raccoon	80	1762	10-14-73	1448-16032	366	234	45.23	31.66	21.04	8.29
							(3.00)	(3.81)	(4.47)	(5.89)
							+44.36	+31.02	+20.91	+9.00
Rend	29	1735	10-14-73	1448-16035	9,765	6,242	37.71	24.52	15.18	6.39
							(3.20)	(3.86)	(5.68)	(6.27)
							+37.08	+23.77	+15.36	+7.32
Rice	35		10-15-73	1449-16084	976	625	37.91	24.90	21.96	9.98
							(3.18)	(2.62)	(6.77)	(6.03)
			10-16-73	1450-16142	947	605	37.00	25.28	20.70	8.68
							(1.65)	(1.85)	(3.74)	(5.62)
							+39.48	+26.06	+20.36	+8.99

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Round	66		10-14-73	1448-16023	147	94	37.21 (1.57) +36.59	21.39 (2.23) +20.59	13.11 (5.25) +13.40	5.75 (6.39) +6.76
Saganashkee	21		10-14-73	1448-16023	229	146	36.34 (1.48) +35.75	22.27 (1.94) +21.48	17.49 (4.12) +17.55	6.97 (5.73) +7.83
			10-15-73	1449-16082	262	167	37.27 (1.52)	23.69 (2.02)	19.30 (5.12)	9.24 (6.62)
Sahara Coal Company	175		10-14-73	1448-16035	153	98	49.09 (3.16) +48.10	40.58 (4.11) +40.09	34.35 (4.25) +33.52	24.19 (3.61) +23.03
St. Mary's	146		10-14-73	1448-16023	65	42	41.72 (2.84) +40.96	23.98 (2.47) +23.22	21.86 (4.85) +21.69	11.81 (7.61) +12.10
Sam Dale State	124		10-14-73	1448-16032	111	71	35.02 (2.56) +34.47	20.13 (3.29) +19.31	16.93 (6.58) +17.02	8.91 (7.28) +9.54
Sam Parr State	41		10-14-73	1448-16032	82	52	36.23 (2.43) +35.64	21.18 (2.82) +20.37	21.18 (6.07) +21.05	14.31 (7.46) +14.31

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Sand	147		10-14-73	1448-16023	61	39	35.85 (1.74)	19.59 (1.66)	13.85 (5.43)	6.39 (6.38)
							+35.27	+18.76	+14.10	+7.32
Sanganois Conservation Area (Muscooten, Sangamon, Treadway)	9		10-15-73	1449-16084	928	594	43.37 (5.68)	34.14 (8.25)	33.71 (7.47)	16.49 (6.44)
			10-16-73	1450-16142	666	426	45.11 (3.99)	36.60 (5.42)	29.89 (4.18)	15.22 (5.86)
							+45.39	+34.86	+26.02	+13.19
Sangchris	11		10-15-73	1449-16084	1,701	1,089	38.07 (3.83)	26.60 (6.02)	24.72 (12.26)	14.70 (9.51)
Sara	26		10-14-73	1448-16032	308	197	35.18 (2.76)	19.89 (3.36)	16.48 (7.05)	10.92 (8.39)
							+34.63	+19.06	+16.59	+11.32
Sawmill	103		10-15-73	1449-16082	359	230	39.64 (1.86)	28.52 (1.65)	24.13 (3.32)	10.60 (4.24)
Senachwine	104		10-15-73	1449-16082	2,508	1,603	41.87 (2.15)	30.45 (1.78)	21.78 (2.86)	7.99 (3.73)
			10-16-73	1450-16140	1,892	1,209	40.31 (2.14)	31.05 (1.98)	25.21 (2.23)	12.19 (3.60)
							+41.89	+30.55	+23.14	+11.27

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Shelbyville	114	1739	10-14-73	1448-16032	6,796	4,343	37.59 (3.03)	24.24 (4.12)	15.26 (6.23)	7.10 (7.07)
							+36.96	+23.48	+15.44	+7.95
			10-15-73	1449-16084	7,715	4,938	36.76 (4.07)	24.50 (5.19)	19.37 (11.03)	9.60 (7.75)
Skokie Lagoons	22		10-14-73	1448-16023	122	80	41.31 (2.91)	27.86 (3.79)	27.42 (5.11)	17.44 (7.41)
							+40.56	+27.16	+26.96	+17.07
			10-15-73	1449-16082	131	84	46.35 (3.87)	31.35 (4.02)	30.87 (4.81)	19.80 (6.37)
Slocum	54	1758	10-14-73	1448-16023	138	88	40.71 (1.85)	22.68 (1.50)	26.47 (2.84)	9.46 (4.72)
							+39.98	+21.90	+26.06	+10.03
Snyder's Hunting Club	142		10-14-73	1448-16035	27	17	36.81 (2.31)	23.25 (3.31)	20.14 (6.55)	14.33 (7.58)
							+36.20	+22.48	+20.06	+14.33
			10-15-73	1449-16093	27	17	34.48 (1.79)	22.29 (2.10)	19.37 (6.28)	13.74 (8.27)
South Wilmington Fireman's Beach and Park	140		10-14-73	1448-16023	155	99	47.02 (3.42)	28.26 (4.90)	20.87 (7.11)	14.56 (7.48)
							+46.09	+27.57	+20.75	+14.53
			10-15-73	1449-16082	158	101	46.65 (3.74)	28.49 (4.65)	21.72 (6.93)	15.11 (7.74)

(continu ed)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Spring	4		10-15-73	1449-16082	211	135	39.54	27.96	24.04	12.14
							(2.18)	(2.31)	(4.31)	(6.64)
			10-16-73	1450-16140	214	137	37.93	27.86	24.72	13.64
							(1.82)	(2.20)	(3.68)	(5.64)
							+40.15	+28.06	+22.84	+12.19
Spring	8		10-16-73	1450-16140	1,689	1,079	40.43	31.09	23.79	10.51
							(2.80)	(3.31)	(3.62)	(5.23)
							+41.98	+30.58	+22.26	+10.20
Spring	67		10-16-73	1450-16142	151	97	40.97	31.39	23.14	12.13
							(2.50)	(2.22)	(4.21)	(6.81)
							+42.37	+30.81	+21.86	+11.23
Spring	118		10-15-73	1449-16084	845	541	37.32	23.74	21.54	10.90
							(3.30)	(3.35)	(7.04)	(7.64)
			10-16-73	1450-16142	790	505	37.02	23.95	20.21	8.61
							(1.99)	(2.41)	(3.83)	(5.96)
							+39.49	+25.02	+20.06	+9.00
Spring Arbor	143		10-14-73	1448-16035	24	15	37.45	21.99	20.58	14.37
							(2.08)	(2.27)	(5.47)	(7.17)
							+36.82	+21.20	+20.48	+14.36
			10-15-73	1449-16093	27	17	34.62	19.66	19.14	14.22
							(1.93)	(2.39)	(6.08)	(7.31)
Springfield	112	1742	10-15-73	1449-16084	2,435	1,558	37.48	23.96	18.02	8.18

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Stephen A. Forbes	78		10-14-73	1448-16032	272	174	36.18	20.79	16.43	9.24
							(3.95)	(3.99)	(6.63)	(7.95)
							+35.59	+19.98	+16.55	+9.84
Storey	50	1751	10-16-73	1450-16142	70	45	37.38	22.48	19.62	11.42
							(2.81)	(2.92)	(6.69)	(8.09)
							+39.75	+23.88	+19.07	+10.78
Sugar Creek (Curry)	178		10-15-73	1449-16084	59	38	45.15	36.31	31.63	15.47
							(4.55)	(5.57)	(4.85)	(4.83)
			10-16-73	1450-16142	54	35	45.96	38.11	32.42	16.98
							(2.29)	(3.47)	(2.64)	(4.62)
							+46.01	+36.04	+27.58	+14.30
Summerset	186		10-15-73	1449-16082	144	92	35.17	19.85	15.95	7.86
							(2.31)	(2.51)	(4.76)	(5.43)
			10-16-73	1450-16142	147	94	31.75	18.34	14.30	8.00
							(1.68)	(2.20)	(4.40)	(5.74)
							+35.65	+20.66	+16.42	+8.61
Sunfish	126		10-16-73	1450-16140	89	57	38.12	28.20	23.31	13.34
							(1.63)	(1.66)	(4.96)	(7.49)
							+40.29	+28.33	+21.97	+12.00
Swan	93		10-16-73	1450-16140	35	22	42.51	32.57	29.99	21.59
							(2.53)	(2.57)	(3.41)	(5.25)
							+43.49	+31.73	+26.08	+17.23

(continu ed)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Swan	172		10-15-73	1449-16082	198	127	39.70	28.17	23.17	10.89
							(2.00)	(1.95)	(4.08)	(6.60)
Tampier	23		10-14-73	1448-16023	140	90	39.22	25.38	20.94	11.31
							(3.46)	(4.31)	(6.62)	(7.57)
							+38.54	+24.64	+20.64	+11.66
			10-15-73	1449-16082	147	94	39.15	25.27	21.15	12.05
							(3.14)	(3.70)	(5.58)	(7.14)
Third	155		10-14-73	1448-16023	99	63	34.60	20.16	16.08	7.21
							(1.58)	(2.36)	(5.48)	(7.08)
							+34.06	+19.34	+16.22	+8.05
Thunderbird	173		10-15-73	1449-16082	57	37	37.57	21.82	17.45	11.64
							(3.14)	(3.35)	(7.43)	(6.88)
			10-16-73	1450-16140	60	38	34.98	19.28	16.29	12.04
							(2.14)	(2.65)	(5.52)	(7.19)
							+38.00	+21.39	+17.65	+11.17
Turner	102		10-15-73	1449-16062	147	94	39.54	27.92	24.12	11.24
							(1.89)	(1.76)	(3.42)	(5.10)
Upper Smith	180		10-15-73	1449-16084	184	118	40.83	28.73	24.59	11.15
							(3.21)	(2.93)	(7.80)	(6.52)
			10-16-73	1450-16142	160	102	41.41	29.96	23.22	10.65
							(2.14)	(1.72)	(4.03)	(6.17)
							+42.69	+29.70	+21.91	+10.29

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Vandalia City	27	1764	10-14-73	1448-16032	394	252	39.15 (4.07) +38.47	24.16 (4.30) +23.40	17.47 (6.78) +17.53	9.46 (8.01) +10.03
We-Ma-Tuk	33	1761	10-15-73	1449-16084	117	75	40.75 (4.41)	29.45 (4.96)	30.70 (12.28)	16.56 (8.23)
			10-16-73	1450-16142	86	55	38.04 (3.72) +40.24	26.81 (4.45) +27.25	21.26 (6.31) +20.71	13.12 (7.89) +11.86
West Frankfort New	31		10-14-73	1448-16035	100	64	34.72 (1.85) +34.18	19.92 (2.21) +19.09	14.70 (5.60) +14.91	7.39 (6.68) +8.20
West Frankfort Old	30		10-14-73	1448-16035	87	56	33.59 (1.53) +33.09	18.89 (2.03) +18.05	17.42 (7.02) +17.48	10.03 (7.78) +10.53
West Loon	156		10-14-73	1448-16023	109	70	35.66 (3.07) +35.09	19.56 (4.22) +18.73	13.00 (7.51) +13.30	6.41 (7.17) +7.34
Wildwood	162		10-15-73	1449-16084	124	79	39.52 (3.25)	22.62 (3.83)	16.73 (6.79)	10.24 (7.09)
Wolf	17		10-14-73	1448-16023	702	449	36.17 (4.75) +35.58	21.73 (6.87) +20.93	15.85 (8.82) +16.00	9.08 (8.44) +9.69

(continued)

TABLE A-1. (continued)

Name of Water Body	Serial Number	NES STORET Number	LANDSAT Scene Date	LANDSAT Scene Number**	Pixels	Area (ha)	LANDSAT MSS Mean DN Value and (Deviation) GRN	RED	IR1	IR2
Wonder	69	1750	10-15-73	1449-16082	442	283	37.29	23.90	19.75	9.50
							(1.95)	(2.03)	(4.35)	(6.22)
Worley	117		10-15-73	1449-16084	137	88	39.45	27.77	27.18	13.00
							(2.94)	(2.34)	(6.81)	(5.88)
			10-16-73	1450-16142	158	101	39.17	28.78	27.57	13.77
							(1.95)	(2.01)	(3.25)	(4.97)
							+41.06	+28.78	+24.59	+12.27
Yorky	179		10-15-73	1449-16084	257	165	40.37	29.39	27.23	11.81
							(3.51)	(3.61)	(8.39)	(5.95)
			10-16-73	1450-16142	236	151	42.19	31.79	25.40	11.92
							(2.17)	(1.93)	(3.25)	(5.53)
							+43.26	+31.12	+23.26	+11.10
Zurich	154		10-14-73	1448-16023	146	93	35.01	19.38	12.08	5.24
							(2.08)	(2.48)	(4.92)	(5.36)
							34.46	18.54	12.43	6.31

*A water body's mean DN value for a particular band was calculated by summing the band's DN value for each pixel and then dividing the sum by the total number of pixels.

**The multispectral scanner data from LANDSAT Scene 1449-16084 are known to be in error, a consequence of missing calibration data, and were not used in model development or for predictive purposes.

+Multispectral scanner data adjusted to a common date (October 15th) through the use of regression models.

TABLE A-2. TROPHIC INDICATOR MEAN VALUES FOR 31 WATER BODIES SAMPLED OCTOBER 16-19, 1973

Name of Water Body	Serial Number	NES STORET Number	CHLA (µg/liter)	COND (µmhos/cm)	SEC (m)	TPHOS (mg/liter)	TON (mg/liter)
Baldwin	105	1763	11.9	457	0.94	0.045	0.714
Bloomington	71	1703	56.8	389	0.79	0.044	0.707
Carlyle	14	1706	19.9	359	0.48	0.091	0.742
Cedar	55	1759	5.6	302	2.77	0.053	1.105
Charleston	16	1708	18.0	519	0.25	0.207	1.200
Coffeen	94	1711	5.8	521	1.37	0.055	0.469
Crab Orchard	127	1712	46.7	235	0.36	0.114	0.843
Decatur	73	1714	21.4	435	0.46	0.143	0.590
DePue	3	1752	42.4	590	0.15	0.499	2.020
East Loon	53	1757	26.8	354	0.91	0.087	1.380
Fox	60	1755	37.4	472	0.36	0.212	0.970
Grass	61	1756	46.1	501	0.31	0.347	1.773
Highland Silver	77	1740	5.8	191	0.41	0.107	0.651
Holiday	51	1754	67.0	473	0.46	0.173	1.200
Horseshoe	131	1766	99.5	547	0.56	0.098	2.375
Long	52	1725	61.2	581	0.31	0.785	2.074
Lou Yaeger	95	1726	8.6	200	0.43	0.150	0.651
Marie	62	1727	70.7	467	0.56	0.286	1.896
Old Ben Mine	32	1765	24.6	1376	0.48	0.930	1.690
Pistakee	65	1733	66.5	467	0.31	0.216	1.635
Raccoon	80	1762	10.6	188	0.41	0.145	0.900
Rend	29	1735	15.6	281	0.61	0.065	0.971
Sangchris	11	1753	15.6	399	0.89	0.047	0.547
Shelbyville	114	1739	12.8	384	0.48	0.063	0.595
Slocum	54	1758	241.4	622	0.31	1.330	5.940
Springfield	112	1742	17.4	318	0.56	0.095	0.595
Storey	50	1751	30.0	408	0.89	0.125	0.980
Vandalia	27	1764	13.5	170	0.71	0.175	1.019

(continued)

TABLE A-2. (continued)

Name of Water Body	Serial Number	NES STORET Number	CHLA (μg/liter)	COND (μmhos/cm)	SEC (m)	TPHOS (mg/liter)	TON (mg/liter)
Vermilion	122	1748	27.0	464	0.36	0.117	0.740
We-Ma-Tuk	33	1761	8.3	758	1.07	0.103	0.588
Wonder	69	1750	198.0	523	0.46	0.423	1.788

TABLE A-3. TROPHIC INDICATOR ANNUAL MEAN VALUES FOR 31 WATER BODIES SAMPLED THREE TIMES DURING 1973

Name of Water Body	Serial Number	NES STORET Number	CHLA (µg/liter)	COND (µmhos/cm)	SEC (m)	TPHOS (mg/liter)	TON (mg/liter)
Baldwin	105	1763	11.3	499	0.99	0.043	0.720
Bloomington	71	1703	26.2	448	0.89	0.064	0.717
Carlyle	14	1706	17.4	379	0.56	0.088	0.885
Cedar	55	1759	5.8	380	2.54	0.035	1.086
Charleston	16	1708	12.0	564	0.23	0.155	0.785
Coffeen	94	1711	7.7	514	1.12	0.045	0.533
Crab Orchard	127	1712	59.9	256	0.46	0.125	1.162
Decatur	73	1714	43.0	518	0.51	0.126	0.682
DePue	3	1752	58.8	703	0.25	0.542	1.478
East Loon	53	1757	22.3	446	1.27	0.102	1.239
Fox	60	1755	63.8	525	0.36	0.225	1.823
Grass	61	1756	83.5	564	0.48	0.280	1.874
Highland Silver	77	1740	5.8	205	0.28	0.225	0.960
Holiday	51	1754	51.2	594	0.38	0.180	1.441
Horseshoe	131	1766	182.2	567	0.43	0.164	2.832
Long	52	1725	49.3	596	0.43	0.580	1.638
Lou Yaeger	95	1726	10.7	207	0.25	0.214	0.674
Marie	62	1727	39.5	488	0.81	0.148	1.476
Old Ben Mine	32	1765	31.4	645	0.56	0.760	1.308
Pistakee	65	1733	75.9	524	0.36	0.203	1.680
Raccoon	80	1762	19.2	260	0.41	0.119	1.091
Rend	29	1735	23.5	306	0.74	0.070	0.960
Sangchris	11	1753	19.3	398	0.64	0.069	0.584
Shelbyville	114	1739	17.2	430	0.99	0.075	0.654
Slocum	54	1758	221.1	676	0.33	0.819	4.398
Springfield	112	1742	13.0	373	0.43	0.123	0.601
Storey	50	1751	17.2	455	1.04	0.093	0.976
Vandalia	27	1764	11.3	179	0.56	0.150	0.882

(continued)

TABLE A-3. (continued)

Name of Water Body	Serial Number	NES STORET Number	CHLA (µg/liter)	COND (µmhos/cm)	SEC (m)	TPHOS (mg/liter)	TON (mg/liter)
Vermilion	122	1748	31.1	546	0.48	0.112	0.821
We-Ma-Tuk	33	1761	8.0	907	0.86	0.071	0.730
Wonder	69	1750	98.5	610	0.36	0.430	1.599

TABLE A-4. TROPHIC INDICATOR AND MULTIVARIATE TROPHIC INDEX ESTIMATES FOR 145 ILLINOIS LAKES BASED ON SET THREE REGRESSION MODELS

Lake Name	Serial Number	Trophic Indicators				Multivariate Trophic Indices	
		SEC (m)	CHLA (µg/liter)	TON (mg/liter)	TPHOS (mg/liter)	PC1Y5 (dimensionless)	PC1F5 (dimensionless)
Anderson	34	0.3	32	2.29	0.22	0.70	2.54
Apple Canyon	144	1.4	35	0.93	0.12	-1.11	0.62
Argyle	157	1.1	3	0.60	0.17	-2.45	-0.68
Bakers	19	0.2	18	4.62	1.02	0.14	4.24
Bangs	56	1.0	38	0.87	0.11	-1.20	0.27
Bath	166	0.3	3	1.37	0.64	-0.66	1.90
Big	134	0.4	18	0.98	0.22	-0.32	1.51
Big	176	0.3	12	1.30	0.26	0.06	2.26
Bracken	145	1.7	42	0.78	0.16	-1.27	0.38
Calumet	18	0.3	29	2.51	0.08	-3.55	0.64
Canton	36	0.5	6	0.78	0.09	-1.45	0.50
Carbondale	38	0.2	1	2.92	1.18	-0.68	3.09
Carlyle	14	0.5	14	0.66	0.06	-1.61	-0.33
Catherine	58	1.1	67	1.35	0.19	-0.17	1.32
Cattail	125	0.8	3	1.03	2.49	-0.90	0.73
Cedar	39	0.5	2	0.91	0.45	-0.80	0.97
Cedar	55	1.4	8	1.23	0.07	-2.55	-0.12
Centralia	79	1.5	24	1.04	0.22	-1.15	0.61
Chain	83	0.3	16	1.47	0.40	0.43	2.67
Channel	59	0.7	91	1.22	0.22	0.89	1.99
Charleston	16	0.3	19	1.33	0.31	0.78	2.65
Chautauqua	87	0.2	15	1.59	0.35	0.53	2.85
Clear	86	0.3	22	1.49	0.36	0.70	2.83
Coal City Recreation Club	138	24.9	2	0.44	0.36	-7.43	-4.83
Commonwealth Edison-Dresden Nuclear	137	0.3	11	0.72	0.12	-0.26	0.69

(continued)

TABLE A-4. (continued)

Lake Name	Serial Number	Trophic Indicators				Multivariate Trophic Indices	
		SEC (m)	CHLA (µg/liter)	TON (mg/liter)	TPHOS (mg/liter)	PC1Y5 (dimensionless)	PC1F5
Countryside	148	0.9	71	1.08	0.16	0.20	1.66
Crab Orchard	127	0.5	69	1.00	0.18	0.71	1.72
Crane	85	0.2	1	1.65	0.33	-0.61	2.26
Crooked	149	0.6	108	1.77	0.29	0.20	2.81
Crystal	68	1.2	22	0.80	0.06	-1.95	-0.15
Decatur	73	0.3	32	1.07	0.20	1.01	2.14
Deep	150	2.4	2	0.66	0.03	-4.24	-1.83
DePue	3	0.2	23	1.47	0.39	1.13	2.99
Devil's Kitchen	128	4.4	30	1.47	0.11	-2.08	0.35
Diamond	57	1.1	35	0.69	0.07	-1.53	-0.09
DuQuoin	98	0.6	62	3.80	0.44	1.48	3.35
Dutchman	49	2.3	37	0.83	0.20	-1.48	0.20
East Loon	53	1.0	30	1.40	0.12	-0.76	1.18
Fourth Lake	151	0.2	36	1.32	0.26	1.31	2.87
Fox	60	0.3	70	1.11	0.33	1.76	2.41
Fyre	170	1.1	50	1.19	0.24	-0.11	1.52
Gages	152	1.3	20	0.96	0.09	-1.99	-0.09
George	108	1.9	30	0.67	0.07	-2.02	-0.28
Glen O. Jones	110	3.2	19	0.73	0.04	-2.96	-0.81
Goose	101	0.2	16	2.18	0.60	1.22	3.74
Goose (Village)	139	1.9	18	0.61	2.54	-4.60	-2.49
Grass	61	0.3	38	1.35	0.25	1.37	2.44
Greenville New City	2	0.5	38	1.06	0.17	0.24	1.68
Griswold	158	0.8	45	1.36	0.42	0.41	2.00
Harrisburg	111	0.9	34	1.38	0.27	-0.12	1.59
Highland	153	1.8	10	1.74	0.12	-2.58	0.05
Holiday	51	0.5	51	1.72	0.24	1.04	2.49

(continued)

TABLE A-4. (continued)

Lake Name	Serial Number	Trophic Indicators SEC (m)	CHLA (μg/liter)	TON (mg/liter)	TPHOS (mg/liter)	Multivariate Trophic Indices PC1Y5 (dimensionless)	PC1F5
Horseshoe	1	0.4	48	1.81	0.98	1.32	3.19
Jack, Swan, Grass	165	0.3	39	1.38	0.30	1.21	2.92
Keithsburg	92	1.0	6	0.94	2.34	-1.15	0.40
Kinkaid	40	6.7	28	0.40	0.01	-4.59	-2.56
Kinneman	168	2.7	30	1.42	6.09	-6.18	-2.26
Lake of Egypt	132	1.6	15	0.59	0.04	-2.55	-0.76
Lake of the Woods	115	0.3	15	1.75	0.74	0.55	2.99
Larue-Pine	121	2.0	5	1.98	41.56	-0.59	0.65
Lily	136	0.3	9	1.50	0.98	-1.71	1.38
Lincoln Trail	13	4.5	30	1.35	0.12	-2.11	0.23
Little Grassy	119	3.4	12	0.95	0.04	-3.20	-1.68
Little Swan	185	0.4	5	0.95	0.21	-0.71	1.27
Liverpool	88	0.4	1	1.31	1.05	-1.53	1.24
Long	52	0.4	58	1.51	0.30	1.33	2.39
Long	177	0.3	1	1.44	0.40	-1.00	1.82
Lower Smith	181	0.5	0	0.92	0.36	-1.65	0.64
Lyerla-Autumnal	120	0.7	21	1.17	0.92	-0.64	1.53
Marie	62	0.4	80	1.29	0.26	1.59	2.73
Marion	129	1.1	73	2.27	0.48	0.91	2.64
Marshall	81	0.3	26	1.55	0.48	1.08	3.05
Matanzas	89	0.3	13	1.34	0.28	0.23	2.41
Mattoon	24	0.6	8	0.62	0.05	-1.79	-0.16
McCollum	159	1.4	30	0.85	0.10	0.37	0.37
McGinnis	20	0.2	104	10.59	3.63	3.69	6.85
Meredosia	10	0.2	4	1.84	0.26	-1.14	2.06
Mesa	184	2.0	22	0.76	0.04	-2.41	-0.42
Moscow	164	0.3	19	1.29	0.35	0.17	2.30
Moses	28	1.6	50	2.44	0.56	0.22	2.10

(continued)

TABLE A-4. (continued)

		Trophic Indicators				Multivariate Trophic Indices	
Lake Name	Serial Number	SEC (m)	CHLA (μg/liter)	TON (mg/liter)	TPHOS (mg/liter)	PC1Y5 (dimensionless)	PC1F5
Mound	163	0.4	50	1.34	0.33	1.18	2.72
Murphysboro	37	1.7	34	1.25	0.20	-0.95	0.92
New Pittsfield	100	0.3	1	1.15	0.15	-1.54	1.10
Nippersink	63	0.3	51	1.27	0.28	1.58	2.48
Old Ben Mine	32	0.6	41	1.35	0.49	0.56	2.16
Olney East Fork	106	1.7	29	0.66	0.06	-2.00	-0.28
Olney New	107	1.6	38	1.05	0.56	-0.60	0.95
Open Pond	174	1.3	2	0.87	3.61	-1.72	-0.17
Otter	167	0.7	15	1.00	0.62	-0.48	1.23
Pana	113	0.9	4	0.67	0.23	-1.99	-0.23
Paradise	15	0.4	22	0.92	0.15	0.01	1.50
Paris Twin	25	1.5	36	1.62	0.49	-0.31	1.45
Pekin	116	0.3	2	1.30	0.55	-0.69	1.81
Petite	64	0.4	50	1.08	0.18	0.77	1.99
Pierce	130	1.0	54	0.95	0.13	-0.32	1.19
Pinckneyville	99	0.6	48	0.91	0.13	0.10	1.43
Pistakee	65	0.4	67	1.24	0.25	1.16	2.16
Powerton Cooling	182	0.5	78	0.97	0.22	0.94	1.79
Quiver	90	0.3	9	1.03	0.22	-0.05	1.77
Raccoon	80	0.4	16	0.94	0.10	-0.60	1.23
Rend	29	0.5	12	0.85	0.10	1.07	0.35
Rice	35	0.3	70	1.40	0.30	1.83	3.11
Round	66	1.4	2	0.66	0.05	-3.65	-1.54
Saganashkee	21	0.4	76	1.62	0.33	1.84	3.14
Sahara Coal Company	175	0.7	267	2.23	30.82	-6.51	-2.13
Sam Dale	124	1.0	66	1.90	0.23	0.48	2.23
Sam Parr	41	1.6	58	1.63	1.49	0.37	1.86
Sand	147	1.6	21	0.99	0.08	-2.22	-0.18
Sanganois	9	0.3	3	1.67	0.65	-1.50	1.73

(continued)

TABLE A-4. (continued)

Lake Name	Serial Number	Trophic Indicators				Multivariate Trophic Indices	
		SEC (m)	CHLA (µg/liter)	TON (mg/liter)	TPHOS (mg/liter)	PC1Y5 (dimensionless)	PC1F5
Sara	26	2.4	21	1.15	0.15	-1.82	0.25
Sawmill	103	0.2	51	3.06	0.91	3.00	5.04
Senachwine	104	0.2	58	1.74	0.45	2.72	3.96
Shelbyville	114	0.6	7	0.80	0.07	-1.65	0.03
Skokie Lagoons	22	0.6	5	1.64	5.46	-0.64	1.67
Slocum	54	0.3	253	6.47	1.48	4.31	6.78
Snyder's Hunting	142	0.9	15	1.67	0.96	-0.15	1.45
South Wilmington	140	7.9	1	0.44	0.20	-6.15	-3.75
Spring	4	0.2	30	2.18	1.01	1.73	3.82
Spring	8	0.2	16	1.30	0.28	0.73	2.61
Spring	67	0.4	3	0.95	0.21	-0.71	1.27
Spring	118	0.4	81	1.29	0.26	1.53	2.81
Spring Arbor	143	2.6	31	1.36	0.97	-0.80	0.75
St Mary's	146	1.4	67	0.92	0.32	-0.70	1.14
Stephen A. Forbes	78	1.4	34	1.10	0.11	-1.14	0.74
Storey	50	1.0	45	0.84	0.16	-0.68	0.95
Sugar Creek	178	0.3	15	2.10	1.18	-2.00	1.72
Summerset	186	0.8	64	1.51	0.19	0.33	1.83
Sunfish	126	0.4	11	1.10	0.42	-0.00	1.81
Swan	93	0.8	9	0.92	3.09	-2.84	-0.52
Swan	172	0.2	40	2.09	0.67	2.11	4.00
Tampier	23	0.6	30	1.07	0.41	-0.03	1.65
Third	155	0.7	79	2.37	0.29	1.18	2.73
Thunderbird	173	2.2	11	0.64	0.10	-2.67	-0.84
Turner	102	0.2	46	2.71	0.95	2.51	4.59
Upper Smith	180	0.3	19	1.09	0.20	-0.04	1.89
Vandalia	27	1.1	18	0.70	0.07	-1.70	-0.01
We-Ma-Tuk	33	0.6	10	0.83	0.25	-0.91	0.81
West Frankfort New	31	1.1	26	1.49	0.11	-1.17	0.92

(continued)

TABLE A-4. (continued)

Lake Name	Serial Number	Trophic Indicators				Multivariate Trophic Indices	
		SEC (m)	CHLA (μg/liter)	TON (mg/liter)	TPHOS (mg/liter)	PC1Y5 (dimensionless)	PC1F5
West Frankfort Old	30	1.2	79	3.22	0.40	0.98	2.90
West Loon	156	2.0	3	0.85	0.04	-3.74	-1.21
Wolf	17	1.2	13	0.98	0.08	-1.80	0.21
Wonder	69	0.4	77	1.74	0.37	2.03	3.37
Worley	117	0.3	23	1.92	0.88	1.05	3.37
Yorkey	179	0.3	9	1.29	0.30	-0.13	2.14
Zurich	154	1.6	1	0.99	0.09	-3.86	-1.30

TABLE A-5. GROUP AND INDIVIDUAL LAKE WATER QUALITY AND ANCILLARY DATA VALUES FOR SELECTED ILLINOIS WATER BODIES CLASSIFIED BY COMPLETE LINKAGE CLUSTERING ON FOUR SPECTRAL ATTRIBUTES (GRN, RED, IR1, IR2)

LAKE NAME	No.	SPECTRAL INDEX SIGNATURES				GROUND TRUTH (1977)			OBSERVED PROBLEMS			NES DATA 1973		MORPHOLOGY		HYDRAULIC FACTORS				BIOTA
		Reflectance Scaled %				Suspended solids mg/l		Sec. Depth m.	1- Minimum, 4-Severe					Depth(meters)						
		GRN	RED	IR1	IR2	Tot.	Vol.		Sedi-ments	Algae	Macro-phytes	sec. m.	chla ug/l	Mean	Max.	Watershed equiv.-cm.	Detention time-yr	Vol. loss %/yr-sedim.	Flush-1973 %/vol-Oct.	Algal count 1000/ml.
Centralia	-079	16	18	26	32	15	3	.71	3	3	2	-	-	2.1	7.5	4.7	.8	.18	24	19.7
Harrisburg	-111	14	20	27	28	9	6	.74	2	1	3	-	-	3.1	9.2	26.5	.7	.17	10	.9
Fyre	-170	20	19	29	28	-	-	-	2	2	3	-	-	4.3	11.0	65.1	3.2	.07	4	-
Apple Canyon	-144	21	18	24	24	-	-	-	2	2	3	-	-	9.2	21.4	33.8	1.7	.10	4	-
McCullom	-159	23	20	24	24	-	-	-	2	2	3	-	-	1.2	2.9	14.9	.7	.27	17	-
Dutchman	-049	23	16	28	34	4	2	1.65	1	1	3	-	-	2.3	8.8	25.8	.7	.19	10	.1
Thunderbird	-173	25	21	24	32	-	-	-	1	2	2	-	-	10.7	18.3	7.5	.4	.35	68	-
Bracken	-145	30	21	31	30	-	-	-	2	2	3	-	-	4.2	10.1	12.6	.6	.26	20	-
1a mean		22	19	27	29	9	4	1.04	1.9	1.9	2.7	-	-	4.6	11.2	26.0	1.0	.20	12	6.9
Countryside	-148	25	20	27	19	-	-	-	-	-	-	-	-	2.3	3.7	30.3	1.5	.18	8	-
Pierce	-130	26	22	26	19	11	10	.68	2	3	3	-	-	3.8	11.0	7.6	.4	.43	50	3.4
George	-108	30	21	24	24	7	7	1.40	1	2	2	-	-	7.0	17.7	24.5	1.2	.16	5	1.4
Olney East Fork	-106	31	22	23	22	3	0	2.71	1	2	3	-	-	4.6	12.2	42.8	1.4	.07	12	.9
Lake of Egypt	-132	33	26	22	22	4	2	1.59	2	1	3	-	-	5.6	15.9	76.3	2.2	.03	5	.2
Vandalia	-027	30	28	24	22	8	3	.90	4	2	1	.71	13	4.2	11.3	16.2	.6	.18	8	.4
1b mean		29	23	24	21	7	4	1.40	2.0	2.0	2.4	.71	13	4.6	12.0	32.9	1.3	.18	9	1.2
Bangs	-056	21	16	12	5	16	14	.60	2	2	3	-	-	4.2	7.6	130.1	6.4	.04	2	.6
Crystal	-068	20	17	13	10	3	3	2.26	1	2	2	-	-	4.1	12.5	30.3	1.5	.01	8	.1
Channel	-059	22	18	21	8	-	-	-	1	3	2	-	-	4.2	12.2	-	-	-	-	-
Diamond	-057	30	22	16	8	14	11	.80	2	3	2	-	-	2.9	7.3	109.0	5.4	.05	2	2.6
Long	-052	17	25	19	6	8	8	.87	2	3	2	.31	61	4.0	9.2	5.5	.3	.45	46	2.5
Pistakee	-065	23	26	22	7	-	-	-	3	3	1	.31	66	1.8	9.2	-	-	-	-	-
Rend	-029	23	29	14	6	-	-	-	2	1	2	.61	15	3.0	9.5	18.1	.6	.05	35	-
Shelbyville	-114	22	28	14	10	-	-	-	2	2	1	.48	12	5.8	19.8	9.7	.4	.06	13	-
Holiday	-051	13	23	22	14	-	-	-	3	3	1	-	-	2.7	5.8	2.1	.1	.10	296	-
1c mean		21	23	17	10	10	9	1.13	2.0	2.4	1.8	.43	39	3.6	10.3	43.5	2.0	.11	58	1.4
Kincaid	-040	50	19	17	15	1	0	1.97	1	1	2	-	-	8.6	24.4	56.9	1.7	.04	7	.3
1d mean		50	19	17	15	1	0	1.97	1	1	2	-	-	8.6	24.4	56.9	1.7	.04	7	.3
Cluster 1 mean		25	22	22	19	10	6	1.27	1.9	2.1	2.3	.49	33	4.4	11.6	34.9	1.5	.16	30	2.5

(continued)

TABLE A-5. (continued)

LAKE NAME ·No.		SPECTRAL INDEX SIGNATURES				GROUND TRUTH (1977)			OBSERVED PROBLEMS			NES DATA 1973		MORPHOLOGY		HYDRAULIC FACTORS				BIOTA
		Reflectance Scaled %				Suspended solids mg/l		Sec. Depth m.	1- Minimum,4-Severe					Depth(meters)						
		GRN	RED	IR1	IR2	Tot.	Vol.		Sedi-ments	Algae	Macro-phytes	sec. m.	chla ug/l	Mean	Max.	Watershed equiv.-cm.	Detention time-yr	Vol. loss %/yr-sedim.	Flush-1973 %/vol-Oct.	Algal count 1000/ml.
Petite	-064	30	34	28	14	-	-	-	3	3	1	-	-	2.3	6.7	-	-	-	-	-
Pinckneyville	-099	34	32	28	15	3	1	2.49	1	2	3	-	-	3.7	8.5	19.8	.6	.20	26	.4
Marie	-062	30	32	31	13	-	-	-	2	3	2	.56	70	2.8	10.7	-	-	-	-	-
Crab Orchard	-127	30	29	24	8	26	17	.52	3	3	2	.36	47	2.8	7.5	17.7	.5	.08	22	25.6
Powerton Cooling	-182	33	30	24	6	-	-	-	1	2	1	-	-	-	-	-	-	-	-	-
Grass	-061	22	35	24	9	-	-	-	4	3	3	.31	46	0.8	1.8	-	-	-	-	-
Nippersink	-063	25	35	24	7	-	-	-	4	3	1	-	-	.9	2.1	-	-	-	-	-
2a mean		29	32	26	10	14	9	1.51	2.6	2.7	1.9	.40	54	2.2	6.2	18.7	.6	.14	24	13.0
Saganashkee	-021	24	29	33	18	54	33	.14	1	2	2	-	-	1.2	2.7	11.0	.5	.34	58	1.8
Wonder	-069	24	30	35	19	49	16	.31	3	3	3	.46	198	3.8	10.4	12.7	.6	.08	20	2.2
Greenville New C	-002	27	31	28	19	15	6	.73	2	2	1	-	-	4.0	7.5	13.9	.6	.05	9	11.8
Rice	-035	36	39	38	16	-	-	-	3	3	1	-	-	.8	1.4	17.4	.9	.06	37	-
Spring	-118	36	35	36	16	-	-	-	4	2	2	-	-	1.4	3.4	44.1	2.1	-	14	-
Mound	-163	34	38	40	24	-	-	-	-	-	-	-	-	.6	-	-	-	-	-	-
2b mean		30	34	35	19	39	18	.39	2.6	2.4	1.8	.46	198	2.2	5.1	19.8	1.0	.13	23	5.3
Griswold	-158	20	24	34	32	27	21	.47	2	2	3	-	-	2.2	3.7	29.1	1.4	.06	9	.4
Old Ben Mine	-032	24	29	38	34	-	-	-	3	3	3	.49	24	1.2	1.5	-	-	-	-	-
Olney New	-107	22	20	36	41	4	2	1.03	2	2	3	-	-	3.4	9.8	21.5	.7	.06	24	3.8
St. Marys	-146	44	27	44	35	-	-	-	-	-	-	-	-	3.1	3.7	30.6	1.5	.05	8	-
Storey	-050	37	30	34	27	15	9	.59	3	3	3	-	-	4.2	11.0	12.4	.6	.09	21	5.3
2c mean		29	27	37	34	15	11	.70	2.5	2.5	3.0	.49	24	2.8	5.7	23.4	.9	.07	14	3.2
Sam Parr	-041	15	15	41	48	3	2	1.65	2	3	2	-	-	3.1	7.0	13.9	.5	.09	29	9.5
Spring Arbor	-143	9	13	32	47	-	-	-	2	2	3	-	-	3.7	15.3	73.2	2.1	.07	5	-
Snyders Hunting	-142	8	23	33	44	-	-	-	2	-	4	-	-	1.2	2.4	6.8	.2	.55	75	-
2d mean		11	17	35	46	3	2	1.65	2.0	2.5	3.0	-	-	2.7	8.2	31.2	1.0	.25	14	9.5
Cluster 2 mean		27	29	33	23	22	12	.88	2.5	2.6	2.3	.43	77	2.4	6.1	23.1	.9	.14	25	7.7

(continued)

TABLE A-5. (continued)

LAKE NAME -No.		SPECTRAL INDEX SIGNATURES				GROUND TRUTH (1977)			OBSERVED PROBLEMS			NES DATA 1973		MORPHOLOGY		HYDRAULIC FACTORS				BIOTA
		Reflectance Scaled %				Suspended solids mg/l		Sec. Depth m.	1- Minimum, 4-Severe					Depth(meters)						
		GRN	RED	IR1	IR2	Tot.	Vol.		Sedi-ments	Algae	Macro-phytes	sec. m.	chla ug/l	Mean	Max.	Watershed equiv.-cm.	Detention time-yr	Vol. loss %/yr-sedim.	Flush-1973 %/vol-Oct.	Algal count 1000/ml.
East Loon	-053	10	14	17	17	2	2	1.53	1	3	3	.91	27	1.8	7.9	4.7	.2	.70	54	2.3
Sam Dale	-124	8	11	22	19	16	7	.81	3	3	3	-	-	2.4	5.5	10.2	.3	.35	50	7.2
Summerset	-186	12	13	17	9	-	-	-	1	2	2	-	-	6.1	14.3	38.6	1.9	.95	10	-
Third	-155	6	11	18	10	-	-	-	2	4	2	-	-	5.7	18.9	90.0	4.4	.43	3	-
Glen O. Jones	-110	18	10	15	20	6	6	1.00	1	3	2	-	-	4.4	9.1	48.1	1.3	.10	5	.8
Mesa	-184	20	14	15	17	-	-	-	1	1	4	-	-	4.0	7.9	67.2	2.2	.07	6	-
Stephen A Forbes	-078	14	14	20	21	12	9	.89	2	2	3	-	-	4.3	8.5	16.2	.6	.18	31	2.9
Wolf	-017	14	18	17	20	8	8	1.47	2	1	3	-	-	2.1	6.4	-	-	-	-	.8
3a mean		13	13	18	17	9	6	1.14	1.6	2.4	2.7	.91	27	3.8	9.8	39.3	1.5	.40	9	2.8
Devils Kitchen	-128	3	0	14	25	0	0	4.52	1	1	1	-	-	11.0	27.4	76.1	2.1	.04	5	.1
Lincoln Trail	-013	5	1	16	27	2	2	2.20	1	2	3	-	-	3.8	12.5	26.2	.9	.18	15	.2
Little Grassy	-119	10	5	10	17	2	1	3.20	1	1	1	-	-	7.8	23.5	81.2	2.3	.04	5	1.0
3b mean		6	2	13	23	1	1	3.31	1.0	1.3	1.7	-	-	7.5	21.1	61.2	1.8	.09	6	.4
Marion	-129	7	12	29	30	6	4	.84	3	4	3	-	-	4.3	7.0	22.6	.6	.18	17	.4
Paris East	-025	8	14	28	37	7	4	1.18	2	2	2	-	-	3.1	8.1	4.0	.2	.74	32	1.5
Moses	-028	2	9	27	35	12	9	.47	2	2	3	-	-	2.7	6.4	23.5	.7	.19	27	23.7
Murphysboro	-037	11	13	23	29	18	15	.51	2	3	1	-	-	4.3	9.8	35.4	1.1	.13	11	6.9
Sara	-026	9	10	20	30	2	1	1.83	1	2	3	-	-	6.1	15.8	47.2	1.9	.07	5	.2
DuQuoin	-098	0	13	24	23	13	12	.59	3	2	3	-	-	2.1	9.1	7.4	.2	.43	86	1.0
West Frankfort O	-030	1	6	24	25	3	3	1.31	1	3	4	-	-	2.4	6.1	13.9	.4	.38	46	2.8
3c mean		5	11	25	30	9	7	.95	2.0	2.6	2.7	-	-	3.6	8.9	22.0	.7	.30	32	5.2
Sand	-147	13	9	8	6	10	8	.84	2	2	3	-	-	3.0	10.1	145.0	7.1	.03	2	.1
West Loon	-156	12	9	4	6	2	2	2.08	1	2	3	-	-	6.4	11.3	211.3	10.4	.03	1	1.3
Deep	-150	18	10	3	4	2	2	2.15	1	1	3	-	-	5.9	15.8	196.2	9.7	.03	1	.2
Zurick	-154	8	8	0	0	5	5	1.24	1	1	2	-	-	3.3	9.8	60.5	3.0	.07	4	.5
Round	-066	20	16	5	3	9	9	.92	2	2	2	-	-	3.5	10.7	150.7	7.4	.03	2	.5
Catherine	-058	12	9	13	5	-	-	-	1	3	2	-	-	5.1	12.2	-	-	-	-	-
Gages	-152	14	12	9	5	7	12	.64	2	3	3	-	-	3.2	14.6	36.1	1.7	.15	7	1.5
Cedar	-055	6	9	7	9	3	3	1.30	1	2	3	2.77	6	1.2	12.2	48.7	1.7	.10	5	.2
West Frankfort N	-031	7	10	12	11	3	2	1.42	1	2	3	-	-	2.4	4.6	10.7	.3	.32	59	.2
Highland	-153	0	2	2	3	-	-	-	1	2	3	-	-	3.2	10.7	50.3	2.5	.43	5	-
3d mean		11	9	6	5	6	5	1.32	1.3	2.0	2.7	2.77	6	3.7	11.2	90.9	4.2	.13	7	.6
Cluster 3 mean		10	10	15	16	7	6	1.43	1.5	2.2	2.6	1.84	17	4.1	11.3	53.8	2.3	.32	19	2.3

(continued)

TABLE A-5. (continued)

LAKE NAME	No.	SPECTRAL INDEX SIGNATURES				GROUND TRUTH (1977)			OBSERVED PROBLEMS			NES DATA 1973		MORPHOLOGY		HYDRAULIC FACTORS				BIOTA
		Reflectance Scaled %				Suspended solids mg/l		Sec. Depth m.	1- Minimum, 4-Severe					Depth(meters)						
		GRN	RED	IR1	IR2	Tot.	Vol.		Sedi-ments	Algae	Macro-phytes	sec. m.	chla ug/l	Mean	Max.	Watershed equiv.-cm.	Detention time-yr	Vol. loss %/yr-sedim.	Flush-1973 %/vol-Oct.	Algal count 1000/ml.
Charleston	-016	48	55	47	25	63	11	.23	4	1	1	.25	18	.9	4.3	.1	.0	8.50	2,083	.2
Spring	-008	50	57	47	23	104	83	.19	3	2	2	-	-	.9	4.3	-	-	-	-	5.4
Quiver	-090	47	55	43	26	127	29	.07	4	2	1	-	-	.8	1.2	-	-	-	-	.2
Little Swan	-185	52	56	45	29	-	-	-	2	3	3	-	-	2.4	9.5	10.9	.5	.30	35	-
Spring	-067	52	58	45	29	17	4	.71	3	2	1	-	-	3.2	10.7	6.8	.3	.42	56	2.4
Chain	-083	53	56	53	29	-	-	-	4	2	1	-	-	-	-	-	-	-	-	-
Clear	-086	52	55	51	26	-	-	-	4	2	1	-	-	.5	.9	-	-	-	-	-
Moscow	-164	52	53	50	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4a mean		51	56	48	27	78	32	.30	3.4	2.0	1.4	.25	18	1.4	5.1	5.9	.3	3.07	725	2.1
Depue	-003	45	53	48	26	-	-	-	3	3	1	.15	58	.9	1.8	-	-	-	-	-
Marshall	-081	44	50	50	29	120	27	.11	4	1	2	-	-	.3	1.5	-	-	-	-	1.0
Big	-134	47	48	43	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourth	-151	47	53	43	17	-	-	-	2	1	3	-	1.2	1.8	45.0	2.2	.12	6	-	
Jack, Swan, Gras	-165	46	49	45	21	-	-	-	4	-	1	-	-	1.2	-	-	-	-	-	-
4b mean		46	51	46	24	120	27	.11	3.3	1.7	1.7	.15	58	.8	1.6	45.0	2.2	.12	6	1.0
Anderson	-034	57	56	46	18	95	37	.12	3	3	1	-	-	1.1	1.6	43.4	2.1	.10	18	71.3
Upper Smith	-180	54	54	45	24	-	-	-	2	2	2	-	-	1.2	1.8	-	-	-	-	-
Canton	-036	57	55	40	24	15	7	.75	3	3	2	-	-	4.3	10.7	11.1	.6	.26	57	3.7
Raccoon	-080	63	59	40	16	22	6	.59	3	2	3	.41	10	1.2	3.7	3.9	.1	.60	129	1.5
Senachwine	-104	49	57	44	10	97	40	.10	4	2	1	-	-	.3	1.5	-	-	-	-	.7
4c mean		56	56	43	18	57	23	.39	3.0	2.4	1.8	.41	10	1.6	3.9	19.5	.9	.32	98	19.3
Decatur	-073	34	43	29	12	36	12	.28	4	2	1	.46	43	2.2	7.0	1.1	.1	5.00	112	5.8
Fox	-060	34	38	27	4	-	-	-	3	3	1	.36	38	1.7	6.7	.4	-	-	-	-
Mattoon	-024	46	45	28	18	12	4	.55	2	2	2	-	-	3.2	10.7	9.6	.4	.23	13	6.2
Paradise	-015	34	44	34	20	33	11	.23	4	1	2	-	-	2.3	7.0	3.5	.1	.80	37	.3
Commonwealth Edi	-137	46	53	24	5	-	-	-	-	-	-	-	-	1.8	4.9	-	-	-	-	-
Carlyle	-014	68	59	27	4	-	-	-	2	2	1	.48	20	3.3	10.7	5.0	.2	.06	26	-
4d mean		44	47	34	11	27	9	.34	3.0	2.0	1.4	.43	33	2.4	7.8	3.9	.2	1.52	54	4.1
Cluster 4 mean		49	53	41	21	62	23	.28	3.2	2.1	1.6	.37	31	1.7	4.9	11.7	.6	1.49	234	6.6

(continued)

TABLE A-5. (continued)

LAKE NAME -No.		SPECTRAL INDEX SIGNATURES				GROUND TRUTH (1977)			OBSERVED PROBLEMS			NES DATA 1973		MORPHOLOGY		HYDRAULIC FACTORS				BIOTA
		Reflectance Scaled %				Suspended solids mg/l		Sec. Depth m.	1- Minimum,4-Severe					Depth(meters)						
		GRN	RED	IR1	IR2	Tot.	Vol.		Sedi-ments	Algae	Macro-phytes	sec. m.	chla ug/l	Mean	Max.	Watershed equiv.-cm.	Detention time-yr	Vol. loss %/yr-sedim.	Flush-1973 %/vol-Oct.	Algal count 1000/ml.
Argyle	-157	44	42	37	37	-	-	-	3	2	2	-	-	5.3	11.6	12.1	.6	.45	32	-
Pana	-113	44	44	39	38	4	2	1.90	3	3	2	-	-	4.2	11.6	.2	.0	4.00	758	.2
We-Ma-Tuk	-033	40	44	39	33	-	-	-	2	2	3	1.07	8	1.8	7.6	2.2	.1	.14	289	-
Cedar	-039	40	50	44	39	4	3	1.94	1	2	1	-	-	7.0	12.2	39.4	1.1	.07	10	13.3
Sunfish	-126	40	48	45	34	33	21	.33	2	2	1	-	-	-	1.8	-	-	-	-	1.3
5a mean		42	46	41	36	14	9	1.37	2.2	2.2	1.8	-	-	4.6	9.0	13.5	.5	1.17	272	4.9
Otter	-167	36	39	45	41	-	-	-	3	-	3	-	-	.6	1.2	-	-	-	-	-
Tampier	-023	34	36	41	34	27	14	.33	1	2	1	-	-	1.5	4.9	15.9	.8	.28	40	8.3
Horseshoe	-001	32	36	51	37	27	18	.33	3	3	3	-	-	1.1	1.7	-	-	-	-	14.2
5b mean		34	38	46	37	27	16	.33	2.3	2.5	2.3	-	-	1.1	2.6	15.9	.8	.28	40	11.3
Sawmill	-103	37	49	55	26	-	-	-	4	1	1	-	-	-	-	-	-	-	-	-
Turner	-102	36	47	55	29	-	-	-	-	1	3	-	-	-	-	-	-	-	-	-
Swan	-172	37	48	51	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spring	-004	36	47	55	35	-	-	-	3	1	1	-	-	1.4	3.4	44.1	2.1	.08	14	-
Lake of the Wood	-115	50	54	58	36	-	-	-	4	2	1	-	-	.5	.9	-	-	-	-	-
Worley	-117	45	50	58	36	-	-	-	4	3	1	-	-	.5	.9	-	-	-	-	-
Lyerala-Autumnal	-120	47	42	55	45	31	16	.30	3	3	3	-	-	.9	3.1	15.9	.5	.27	24	2.9
Crooked	-149	66	38	56	24	-	-	-	2	3	2	-	-	4.3	9.8	-	-	-	-	-
5c mean		44	47	55	32	31	16	.30	3.3	2.0	1.7	-	-	1.5	3.6	30.0	1.1	.12	19	2.9
Cattail	-125	35	42	54	58	45	26	.08	3	2	3	-	-	.3	1.5	-	-	-	-	.7
Keithsburg	-092	35	39	52	58	114	72	.09	3	3	2	-	-	.8	1.8	-	-	-	-	7.7
Open Pond	-174	40	41	57	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Skokie Lagoons	-022	42	43	69	64	37	22	.25	4	4	1	-	-	.8	1.8	-	-	-	-	13.8
5d mean		38	41	58	61	65	40	.14	3.3	3.0	2.0	-	-	.6	1.7	-	-	-	-	7.4
McGinnis	-020	30	31	74	39	-	-	-	1	3	4	-	-	.5	1.2	9.0	.5	.48	70	-
Slocum	-054	39	22	65	22	25	21	.34	4	4	1	.31	241	1.2	2.7	4.8	.2	.70	53	30.5
LaRue-Pine	-121	24	27	77	95	-	-	-	2	4	4	-	-	.6	1.8	-	-	-	-	-
5e mean		31	27	72	52	25	21	.34	2.3	3.7	3.0	.31	241	.8	2.0	6.9	.3	.59	62	30.5
Cluster 5 mean		40	42	54	41	32	22	.50	2.7	2.5	2.0	.69	125	1.8	4.3	13.1	.7	.72	143	11.4

(continued)

TABLE A-5. (continued)

LAKE NAME -No.		SPECTRAL INDEX SIGNATURES				GROUND TRUTH (1977)			OBSERVED PROBLEMS			NES DATA 1973		MORPHOLOGY		HYDRAULIC FACTORS				BIOTA
		Reflectance Scaled %				Suspended solids mg/l		Sec. Depth m.	1- Minimum, 4-Severe					Depth(meters)						
		GRN	RED	IR1	IR2	Tot.	Vol.		Sedi-ments	Algae	Macro-phytes	sec. m.	chla ug/l	Mean	Max.	Watershed equiv.-cm.	Detention time-yr	Vol. loss %/yr-sedim.	Flush-1973 %/vol-Oct.	Algal count 1000/ml.
Big	-176	57	60	50	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Matanza	-089	56	60	50	26	68	20	.11	4	2	2	-	-	1.5	2.4	-	-	-	-	-
Yorkey	-179	57	60	51	29	-	-	-	2	-	1	-	-	1.2	4.6	-	-	-	-	-
Chautauqua	-087	57	61	54	26	-	-	-	4	2	1	-	-	.6	1.2	-	-	-	-	-
Goose	-101	53	61	59	28	-	-	-	4	1	1	-	-	-	-	-	-	-	-	-
Bath	-166	56	59	58	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pekin	-116	56	61	57	38	-	-	-	4	1	1	-	-	.5	.9	-	-	-	-	-
Lower Smith	-181	57	61	51	39	-	-	-	2	1	2	-	-	.6	1.2	-	-	-	-	-
Crane	-085	67	72	58	30	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-
Long	-177	65	67	58	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Liverpool	-088	60	66	63	48	-	-	-	4	-	1	-	-	.6	1.2	-	-	-	-	-
Bakers	-019	69	59	76	35	-	-	-	1	2	4	-	-	1.1	4.9	23.1	1.1	.15	11	-
6a mean		59	62	57	33	68	20	.11	3.2	1.5	1.5	-	-	.9	2.3	23.1	1.1	.15	11	-
Lily	-136	65	75	65	47	-	-	-	3	2	1	-	-	1.2	2.1	-	-	-	-	-
Sanganois	-009	68	75	64	41	-	-	-	4	2	1	-	-	-	-	-	-	-	-	-
Carbondale	-038	67	72	73	42	-	-	-	2	2	2	-	-	2.4	6.4	17.2	.5	.25	22	.2
Sugar Creek	-178	72	80	72	48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Meredosia	-010	75	84	60	29	150	39	.11	4	3	1	-	-	.8	1.5	-	-	-	-	164.4
New Pittsfield	-100	71	76	51	28	-	-	-	3	2	1	-	-	3.8	10.3	12.7	-	.25	30	.8
6b mean		70	77	68	39	150	39	.11	3.2	2.2	1.2	-	-	2.0	5.0	14.9	.5	.25	26	55.1
Coal City Recrea	-138	85	49	48	61	-	-	-	2	1	2	-	-	8.7	17.3	-	-	-	-	-
South Wilmington	-140	75	49	44	53	-	-	-	2	1	1	-	-	-	-	-	-	-	-	-
Goose Village	-139	66	63	60	70	-	-	-	2	1	1	-	-	7.6	19.8	-	-	-	-	-
Swan	-093	58	62	65	65	-	-	-	4	2	1	-	-	-	-	.3	.01	-	-	-
6c mean		71	56	54	62	-	-	-	2.5	1.3	1.3	-	-	8.0	18.6	.3	.01	-	-	
Calumet	-018	100	100	60	27	-	-	-	4	1	1	-	-	2.4	3.1	-	-	-	-	-
Kinneman	-168	89	67	81	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sahara Coal Comp	-175	83	97	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6d mean		91	88	80	69	-	-	-	4	1	1	-	-	2.4	3.1	-	-	-	-	-
Cluster 6 mean		67	68	62	44	58	17	.11	3.1	1.6	1.4	-	-	2.4	5.5	13.2	.56	.22	21	55.1

RC:mr/4848/sp